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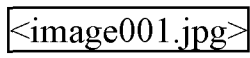
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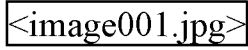
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On Wed, Jul 23, 2025 at 2:19 PM Ross McKittrick <ross.mckittrick@gmail.com> wrote:

Attached in MSWord and PDF formats.

All of Steve's corrections incorporated, also John's stray L and everything else I'm aware of. The only remaining correction I have not been able to make is using a high-res version of the DoE logo. If that becomes the main focus of public criticism I will say we did well.

Ross

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<image001.jpg>

Judith Curry, President
CFAN - Climate Forecast Applications Network
Reno, NV USA

curry.judith@cfanclimate.com | +1.404.803.2012
http://www.cfanclimate.net

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<CWG Press Release.docx>

From: Roy Spencer <roywspencer@hotmail.com>
Sent: Tuesday, July 29, 2025 6:31 AM
To: Ross McKittrick; Steven Koonin
Cc: John Christy; Fisher, Travis; Judith Curry; Loucks, Joshua; Cohen, Seth
Subject: Report references totals

In case allegations of a "minority" viewpoint come up, this might help offset that:

In our report, there are:

350 references, of which
23 have us as lead- or co-authors

So, only **6.6%** of the reference mentions in the report come from OUR research. (Those are the total reference mentions, including double- or triple-counting).

By the way, Ross wins by a large margin, and John gets an Honorable Mention.

-Roy

From: Ross McKittrick <ross.mckittrick@gmail.com>
Sent: Thursday, July 24, 2025 10:23 AM
To: Steven Koonin <steven.koonin@gmail.com>
Cc: John Christy <climateman60@gmail.com>; Roy Spencer <roywspencer@hotmail.com>; Fisher, Travis <travis.fisher@hq.doe.gov>; Judith Curry <curry.judith@gmail.com>; Loucks, Joshua <Joshua.Loucks@hq.doe.gov>; Cohen, Seth <seth.cohen@hq.doe.gov>
Subject: Re: [EXTERNAL] RE: July 23rd version - final (?)

PS here are the report files now with a hi-res logo included.

On Thu, Jul 24, 2025 at 10:18 AM Steven Koonin <steven.koonin@gmail.com> wrote:

If you want to shorten Ross' proposed title a bit, it could read:

Department of Energy Releases Report That Challenges Common Misconceptions About Climate Change

From: Ross McKittrick <ross.mckittrick@gmail.com>
Sent: Thursday, July 24, 2025 11:16 AM
To: John Christy <climateman60@gmail.com>
Cc: Steven Koonin <steven.koonin@gmail.com>; Roy Spencer <roywspencer@hotmail.com>; Fisher, Travis <travis.fisher@hq.doe.gov>; Judith Curry <curry.judith@gmail.com>; Loucks, Joshua <Joshua.Loucks@hq.doe.gov>; Cohen, Seth <seth.cohen@hq.doe.gov>
Subject: Re: [EXTERNAL] RE: July 23rd version - final (?)

The title might need to say a bit more, e.g.

Department of Energy Releases Report of Climate Working Group That Challenges Common Misconceptions About Climate Change

and then the remainder follows the text as shown in Steve's edit, with "renowned" replaced by "eminent", there being no adjective that won't draw scorn from the haters, but we might as well pick the word we like best.

On Thu, Jul 24, 2025 at 9:09 AM John Christy <climateman60@gmail.com> wrote:

Looks good.

John C.

On Thu, Jul 24, 2025 at 8:59 AM Steven Koonin <steven.koonin@gmail.com> wrote:

And with me.

SEK

From: Roy Spencer <roywspencer@hotmail.com>

Sent: Thursday, July 24, 2025 9:49 AM

To: Fisher, Travis <travis.fisher@hq.doe.gov>; Steven Koonin <steven.koonin@gmail.com>; 'John Christy' <climateman60@gmail.com>

Cc: 'Judith Curry' <curry.judith@gmail.com>; 'Ross McKittrick' <ross.mckittrick@gmail.com>; Loucks, Joshua <Joshua.Loucks@hq.doe.gov>; Cohen, Seth <seth.cohen@hq.doe.gov>

Subject: RE: [EXTERNAL] RE: July 23rd version - final (?)

Fine with me.

Sent from my Verizon, Samsung Galaxy smartphone

----- Original message -----

From: "Fisher, Travis" <travis.fisher@hq.doe.gov>

Date: 7/24/25 8:42 AM (GMT-06:00)

To: Steven Koonin <steven.koonin@gmail.com>, 'John Christy' <climateman60@gmail.com>

Cc: 'Judith Curry' <curry.judith@gmail.com>, 'Ross McKittrick' <ross.mckittrick@gmail.com>, "Loucks, Joshua" <Joshua.Loucks@hq.doe.gov>, "Cohen, Seth" <seth.cohen@hq.doe.gov>, "Roy W. Spencer" <roywspencer@hotmail.com>

Subject: RE: [EXTERNAL] RE: July 23rd version - final (?)

Ok I'm going with eminent for now. All of this is subject to review by the office of public affairs, so we'll see what sticks.

In this next iteration I added your bios at the end (straight copy/paste from the report). Are you all comfortable if we decide to take that approach?

From: Steven Koonin <steven.koonin@gmail.com>
Sent: Thursday, July 24, 2025 9:21 AM
To: Fisher, Travis <travis.fisher@hq.doe.gov>; 'John Christy' <climatemanager60@gmail.com>
Cc: 'Judith Curry' <curry.judith@gmail.com>; 'Ross McKittrick' <ross.mckittrick@gmail.com>; Loucks, Joshua <Joshua.Loucks@hq.doe.gov>; Cohen, Seth <seth.cohen@hq.doe.gov>; 'Roy W. Spencer' <roywspencer@hotmail.com>
Subject: RE: [EXTERNAL] RE: July 23rd version - final (?)

Perhaps “eminent” .

Although in some eyes, “notorious” would be appropriate.

From: Fisher, Travis <travis.fisher@hq.doe.gov>
Sent: Thursday, July 24, 2025 9:07 AM
To: John Christy <climatemanager60@gmail.com>
Cc: Steven Koonin <steven.koonin@gmail.com>; Judith Curry <curry.judith@gmail.com>; Ross McKittrick <ross.mckittrick@gmail.com>; Loucks, Joshua <Joshua.Loucks@hq.doe.gov>; Cohen, Seth <seth.cohen@hq.doe.gov>; Roy W. Spencer <roywspencer@hotmail.com>
Subject: RE: [EXTERNAL] RE: July 23rd version - final (?)

I don’t want anyone to think of you all as circus performers! I was looking for a synonym for “distinguished,” with the bonus of being well-known. I’m open to ideas: [RENOWNED Synonyms: 104 Similar and Opposite Words | Merriam-Webster Thesaurus](#)

From: John Christy <climatemanager60@gmail.com>
Sent: Thursday, July 24, 2025 8:53 AM
To: Fisher, Travis <travis.fisher@hq.doe.gov>
Cc: Steven Koonin <steven.koonin@gmail.com>; Judith Curry <curry.judith@gmail.com>; Ross McKittrick <ross.mckittrick@gmail.com>; Loucks, Joshua <Joshua.Loucks@hq.doe.gov>; Cohen, Seth <seth.cohen@hq.doe.gov>; Roy W. Spencer <roywspencer@hotmail.com>
Subject: Re: [EXTERNAL] RE: July 23rd version - final (?)

Travis

“Renowned” sounds a little like a circus performer.

I wonder how many reporters will actually read the whole document? I suspect one of our common answers to their questions is, “just read the report!”

John C.

Sent from my iPhone

On Jul 23, 2025, at 8:28 PM, Fisher, Travis <travis.fisher@hq.doe.gov> wrote:

It’s a heck of a report. I can’t wait to see where we go from here!

Here’s my first attempt at a press release—please make any edits or suggestions you like.

From: Steven Koonin <steven.koonin@gmail.com>
Sent: Wednesday, July 23, 2025 5:50 PM
To: 'Judith Curry' <curry.judith@gmail.com>; 'Ross McKittrick' <ross.mckittrick@gmail.com>
Cc: Fisher, Travis <travis.fisher@hq.doe.gov>; Loucks, Joshua <Joshua.Loucks@hq.doe.gov>; Cohen, Seth <seth.cohen@hq.doe.gov>; 'John Christy' <climateman60@gmail.com>; 'Roy W. Spencer' <roywspencer@hotmail.com>
Subject: [EXTERNAL] RE: July 23rd version - final (?)

Second that! Amazing effort, Ross.

SEK

From: Judith Curry <curry.judith@gmail.com>
Sent: Wednesday, July 23, 2025 5:49 PM
To: Ross McKittrick <ross.mckittrick@gmail.com>
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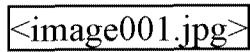
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Ross

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<CWG Press Release.docx>

From: Ross McKittrick <ross.mckittrick@gmail.com>
Sent: Monday, July 14, 2025 1:06 PM
To: Travis Fisher
Cc: Judith Curry; Steven Koonin; John Christy; Roy W. Spencer; Josh Loucks; Seth Cohen
Subject: Re: proposed (slight) rewrite of the CWG25 preface

I'm going through the edition following Steve's and Judy's edits to make a clean copy for final review and approval. I don't think we'll need a meeting for it.

On Mon, Jul 14, 2025 at 12:12 PM Travis Fisher <travis.scott.fisher@gmail.com> wrote:

I agree that they're on different timelines. I'd still urge this group to consider how you want to publish the NCA5 critique when the time comes.

Separately, I plan to remove myself from the sherpa position for this work over the next two weeks (my last day at DOE will be July 31). I have to get back to my position at Cato.

Josh, Seth, and an incoming political appointee in the office of the undersecretary of science at DOE (Ari Boosalis) will move this effort forward.

If anyone wants to connect, please feel free to call my cell at 202-302-9953.

On Mon, Jul 14, 2025 at 11:04 AM Judith Curry <curry.judith@gmail.com> wrote:

Travis, I suspect we can finalize CWG report today (or tomorrow). the NCA5 is not quite ready, we definitely don't want to slow down publication of CWG

On Mon, Jul 14, 2025 at 8:00 AM Travis Fisher <travis.scott.fisher@gmail.com> wrote:

When you all are comfortable with the final (actually final) version of CWG25, would one of you please send it to my DOE email address? It's travis.fisher@hq.doe.gov

I am sorting out the details of a quick, non-binding internal review of CWG25 to satisfy IQA requirements before DOE publishes the document. Publication could be as soon as next week.

We will have to figure out who will publish the NCA5 critique now that GCRP is not a near-term option. Start thinking about whether you might want to publish both documents together or at least through the same DOE channels.

On Mon, Jul 14, 2025 at 10:39 AM Judith Curry <curry.judith@gmail.com> wrote:

looks good to me

On Mon, Jul 14, 2025 at 7:32 AM Steven Koonin <steven.koonin@gmail.com> wrote:

Perhaps Ross is already on top of this, but if not, I'd propose the following rewrite of the second paragraph of the Preface.

It currently reads:

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Sent: Monday, July 14, 2025 12:12 PM
To: Judith Curry
Cc: Steven Koonin; Ross McKittrick; John Christy; Roy W. Spencer; Josh Loucks; Seth Cohen
Subject: Re: proposed (slight) rewrite of the CWG25 preface

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Sent: Monday, July 14, 2025 11:01 AM
To: Judith Curry
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Subject: Re: [EXTERNAL] Re: my new blog post on the history of TX Hill Country floods...

Travis

I have a MS exam 3:30-5:30 ET tomorrow. Friday is clear.

John C.

On Wed, Jul 30, 2025 at 3:51 PM Fisher, Travis <travis.fisher@hq.doe.gov> wrote:

I had to cancel the meeting I was trying to put together today. Sorry about the mix-up!

What does tomorrow afternoon like for everyone? I could do Friday too, but I'll have to join in my Cato capacity.

From: John Christy <climateman60@gmail.com>
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To: Fisher, Travis <travis.fisher@hq.doe.gov>
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Travis

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Cc: Steven Koonin <steven.koonin@gmail.com>; Roy Spencer <roywspencer@hotmail.com>; Ross McKittrick <ross.mckittrick@gmail.com>; Josh Loucks <loucksj14@gmail.com>; Cohen, Seth <seth.cohen@hq.doe.gov>; Fisher, Travis <travis.fisher@hq.doe.gov>

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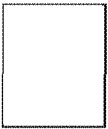
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Sent from my Verizon, Samsung Galaxy smartphone

----- Original message -----

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I had to cancel the meeting I was trying to put together today. Sorry about the mix-up!

What does tomorrow afternoon like for everyone? I could do Friday too, but I'll have to join in my Cato capacity.

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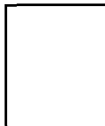
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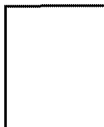
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<http://www.cfanclimate.net>

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From: Fisher, Travis [travis.fisher@hq.doe.gov]
Sent: 7/30/2025 5:56:10 PM
To: Judith Curry [curry.judith@gmail.com]; John Christy [climateman60@gmail.com]; Park, Charles [charles.park@hq.doe.gov]
CC: Steven Koonin [steven.koonin@gmail.com]; Roy Spencer [roywspencer@hotmail.com]; Ross McKittrick [ross.mckittrick@gmail.com]; Cohen, Seth [seth.cohen@hq.doe.gov]; Loucks, Joshua [Joshua.Loucks@hq.doe.gov]
Subject: RE: [EXTERNAL] Re: my new blog post on the history of TX Hill Country floods...

Scratch the meeting request—Charles is not available at 3pm ET today. I'll find another time as soon as I can.

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Cc: Steven Koonin; Roy Spencer; Ross McKittrick; Cohen, Seth; Loucks, Joshua
Subject: [EXTERNAL] Re: my new blog post on the history of TX Hill Country floods...
Attachments: image001.jpg

For anyone able to join, let's huddle briefly with Charles Park in DOE's Office of General Counsel. He'll be part of the broader team moving forward and can help coordinate the effort as it moves through the comment period, external peer review, and final report.

We can do another introductory meeting later for anyone unable to join today.

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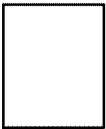
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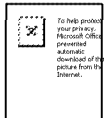
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<414780_190007_Kerrville.pdf>

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Sent: Wednesday, July 30, 2025 10:11 AM
To: Judith Curry
Cc: Steven Koonin; Roy Spencer; Ross McKittrick; Josh Loucks; Seth Cohen; Travis Fisher
Subject: Re: my new blog post on the history of TX Hill Country floods...

Judy

Was Richard referring to your post or to the CGW?

John C.

On Wed, Jul 30, 2025 at 9:04 AM Judith Curry <curry.judith@gmail.com> wrote:
yes, nice blog post

Note: on my blog Richard Tol commented briefly

"not your best work"

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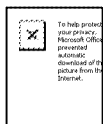
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--
Judith Curry, President
CFAN - Climate Forecast Applications Network
Reno, NV USA
curry.judith@cfanclimate.com | +1.404.803.2012
<http://www.cfanclimate.net>

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Kerrville TX

1	1978	8	2	15.80
2	1900	7	15	13.00
3	1936	9	16	12.37
4	1971	8	13	11.69
5	1919	8	22	11.62
6	1921	6	13	9.06
7	1952	9	11	8.90
8	1909	7	23	8.84
9	1965	6	23	8.25
10	1957	10	15	7.90
11	1997	6	23	7.76
12	2002	7	3	7.73
13	1991	12	21	7.67
14	1910	4	1	7.52
15	1980	9	8	7.35
16	1974	5	1	7.13
17	1920	8	8	6.68
18	1988	7	12	6.38
19	1935	6	15	6.37
20	1932	7	3	6.29
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Sent: Wednesday, July 30, 2025 12:40 PM
To: Steven Koonin; John Christy
Cc: Judith Curry; Travis Fisher; Ross McKittrick
Subject: RE: meanwhile on X

That sounds good. If she wants to use that as a quote in her article, that works, too.
-Roy

Sent from my Verizon, Samsung Galaxy smartphone

----- Original message -----

From: Steven Koonin <steven.koonin@gmail.com>
Date: 7/30/25 11:21 AM (GMT-06:00)
To: John Christy <climateman60@gmail.com>
Cc: Judith Curry <curry.judith@gmail.com>, Travis Fisher <travis.scott.fisher@gmail.com>, Ross McKittrick <ross.mckittrick@gmail.com>, Roy Spencer <roywspencer@hotmail.com>
Subject: Re: meanwhile on X

Right. Here's what I just wrote back to Maxine J at NYT:

Maxine- sound bites produced on short notice filtered through a non-expert reporter are not conducive for serious scientific communication.

If your paper will allow me an OpEd, I can respond to the questions you pose. (BTW, I note the WSJ sometimes publishes OpEds that differ dramatically from its editorial positions.)

In addition, DOE has, or soon will have, a comment portal. I and my coauthors are committed to giving serious responses to all serious criticisms.

Steven E. Koonin

On Jul 30, 2025, at 10:01, John Christy <climateman60@gmail.com> wrote:

The Secretary wants an organized, thoughtful discussion on climate change. I don't see how we can respond to the many claims (and ad hominem) made through the mouthpieces of the environmental pressure groups. We have a chance to advance his wishes through the public comment period. If we've made a mistake, we'll acknowledge it and fix it - that's the story that should carry the day at this point.

John C.

On Wed, Jul 30, 2025 at 10:15 AM Steven Koonin <steven.koonin@gmail.com> wrote:
And please send to me.

Steven E. Koonin

On Jul 30, 2025, at 09:11, Judith Curry <curry.judith@gmail.com> wrote:

sure pls send

On Wed, Jul 30, 2025 at 7:53 AM Travis Fisher <travis.scott.fisher@gmail.com> wrote:

Separate question: do you all want me to relay articles that mention the DOE report?

Example:

<https://www.eenews.net/articles/epa-attacks-climate-science-here-are-the-facts/>

On Wed, Jul 30, 2025 at 10:26 AM Travis Fisher

<travis.scott.fisher@gmail.com> wrote:

This sounds like it might need to be two different calls. I plan to set one up for 3pm today and another one tomorrow or Friday for anyone we missed.

The invitation will come from my DOE account a bit later today.

On Wed, Jul 30, 2025 at 9:55 AM Ross McKittrick

<ross.mckittrick@gmail.com> wrote:

I can be available at 4:30 I think.

On Wed, Jul 30, 2025 at 4:34 AM Roy Spencer

<roywspencer@hotmail.com> wrote:

3-5 pm ET is fine with me.

-Roy

From: John Christy <climateman60@gmail.com>

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Subject: Re: meanwhile on X

I'm available 3-5p ET

John C.

Sent from my iPhone

On Jul 29, 2025, at 10:18 PM, Travis Fisher
<travis.scott.fisher@gmail.com> wrote:

I followed Ross on X and will be popping popcorn for the next few months!

As I transition out of my DOE role, I want to introduce you all to Charles Park, DOE's deputy GC for energy policy (and a nice guy), who I understand will be part of the liaison team between you all and DOE for the external peer review and final draft.

Do you all have any availability between 2pm and 5pm ET tomorrow? I'd like to do a quick video meeting to help everyone get acquainted.

PS - it looked to me like the Secretary had fun talking about this project today. Also, fun fact: when I sent him the updated draft for review, his response was "no need to review—I trust the authors." You all are a special team, and you deserve a medal. Even the Canadian.

On Tue, Jul 29, 2025 at 11:06 PM Steven Koonin
<steven.koonin@gmail.com> wrote:
Embarrassing behavior by scientists.

If we're really so wrong, they should be able to conjure up many specific criticisms. Yet none are forthcoming.

Steven E. Koonin

On Jul 29, 2025, at 21:01, John Christy
<climateman60@gmail.com> wrote:

Hausfather did the same on CNN.

Sent from my iPhone

On Jul 29, 2025, at 9:50 PM,
Roy Spencer
<roywspencer@hotmail.com>
wrote:

Maybe it's a good sign that Mann and Dessler seem to be about the only scientists out of "thousands" that are willing to trash us.

-Roy

From: Ross McKittrick
<ross.mckittrick@gmail.com>
Sent: Tuesday, July 29, 2025 6:48 PM
To: Judith Curry
<curry.judith@gmail.com>; Roy W. Spencer
<roywspencer@hotmail.com>; John Christy
<climateman60@gmail.com>; Steven Koonin
<steven.koonin@gmail.com>; Travis Fisher
<travis.scott.fisher@gmail.com>
Subject: meanwhile on X

To no one's surprise Michael Mann and Andrew Dessler have dismissed the report based on the author names. Fortunately one of the Ruthless podcast hosts hasn't been blocked from Mann's feed and pointed out the problem with relying on Mann
<image.png>



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Sent: Wednesday, July 30, 2025 12:21 PM
To: John Christy
Cc: Judith Curry; Travis Fisher; Ross McKittrick; Roy Spencer
Subject: Re: meanwhile on X

Right. Here's what I just wrote back to Maxine J at NYT:

Maxine- sound bites produced on short notice filtered through a non-expert reporter are not conducive for serious scientific communication.

If your paper will allow me an OpEd, I can respond to the questions you pose. (BTW, I note the WSJ sometimes publishes OpEds that differ dramatically from its editorial positions.)

In addition, DOE has, or soon will have, a comment portal. I and my coauthors are committed to giving serious responses to all serious criticisms.

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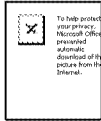
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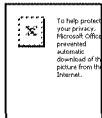
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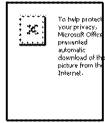
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From: Ross McKittrick <ross.mckittrick@gmail.com>
Sent: Wednesday, July 30, 2025 9:55 AM
To: Roy Spencer
Cc: John Christy; Travis Fisher; Steven Koonin; Judith Curry
Subject: Re: meanwhile on X

I can be available at 4:30 I think.

On Wed, Jul 30, 2025 at 4:34 AM Roy Spencer <roywspencer@hotmail.com> wrote:
3-5 pm ET is fine with me.
-Roy

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Sent: Tuesday, July 29, 2025 10:29 PM
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Subject: Re: meanwhile on X

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John C.

Sent from my iPhone

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To: Steven Koonin
Cc: Travis Fisher; John Christy; Roy Spencer; Judith Curry
Subject: Re: meanwhile on X

Tomorrow afternoon doesn't work for me. On the road most of it. Thursday morning is better.

On Tue, Jul 29, 2025 at 11:32 PM Steven Koonin <steven.koonin@gmail.com> wrote:

If my flights are on time tomorrow I might be able to join a call from the Denver airport between 1430 and 1530 ET. Other times won't work for me.

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Sent: Tuesday, July 29, 2025 11:19 PM
To: Steven Koonin
Cc: John Christy; Roy Spencer; Ross McKittrick; Judith Curry
Subject: Re: meanwhile on X

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To: John Christy
Cc: Roy Spencer; Judith Curry; Steven Koonin; Travis Fisher
Subject: Re: meanwhile on X

Yeah he did the same blog post gag.

The aim of the lefty media is to reassure their followers that there is no reason to read the report.

The fact that Zeke played along revealed exactly who he really is.

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Comfortably Smug @ComfortablySmug · 1m



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Michael E. Mann
@michaelsmann_boky.associa

+ Follow

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🌟 **Andrew Dessler** @andrewdessler.com · 4h

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A Critical Review of Impacts of Greenhouse Gas Emissions on the U.S. Climate

Report to U.S. Energy Secretary Christopher Wright
July 23, 2025

Climate Working Group:

John Christy, Ph.D.
Judith Curry, Ph.D.
Steven Koonin, Ph.D.
Ross McKittrick, Ph.D.
Roy Spencer, Ph.D.

July 29, 2025 at 3:48 PM 🌐 Everybody can reply



From: John Christy <climateman60@gmail.com>
Sent: Tuesday, July 29, 2025 8:57 PM
To: Steven Koonin
Cc: Ross McKittrick; Judith Curry; Roy W. Spencer; Travis Fisher
Subject: Re: meanwhile on X

Sent from my iPhone

> On Jul 29, 2025, at 6:52 PM, Steven Koonin <steven.koonin@gmail.com> wrote:

>

> Expect we'll all take the high ground and not get involved in this kind of name calling.

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> Steven E. Koonin

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Report to U.S. Energy Secretary Christopher Wright
July 25, 2025

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Steven Koonin, Ph.D.
Ross McKittrick, Ph.D.
Roy Spencer, Ph.D.

July 29, 2025 at 3:48 PM Everybody can reply



From: Steven Koonin <steven.koonin@gmail.com>
Sent: Thursday, July 10, 2025 1:15 PM
To: 'John Christy'; 'Ross McKittrick'; 'Roy Spencer'; 'Judith Curry'; 'Josh Loucks'; 'Travis Fisher'
Subject: MS Copilot rebuttal OpEd

I asked MS Copilot to craft a rebuttal OpEd. Here's what it produced. Perhaps worth some pre-emptive wording in our final.
SEK

Here's a draft OpEd rebuttal built to challenge the report's claims while staying accessible, persuasive, and grounded in scientific integrity:

● ***Climate Skepticism Is Not Scientific Rigor: A Rebuttal to the CWG Report***

By [Your Name]

The recently released CWG climate report bills itself as an “independent scientific assessment,” yet its findings read less like a rigorous synthesis and more like a curated skepticism tour. While its authors deserve credit for clear data presentation and a commitment to contrarian inquiry, the document ultimately leans too heavily on selective sourcing, rhetorical framing, and omission of key uncertainties to serve as a balanced scientific review.

Let's dissect where the CWG's thesis falters.

🌱 **CO₂: Beneficial, But Not a Panacea**

The report rightly highlights satellite-confirmed global greening—an intriguing sign of CO₂ fertilization. But it downplays the physiological limits of crops under heat stress, drought, and nutrient scarcity. FACE experiments and agronomic models routinely show that productivity gains from CO₂ alone are muted in real-world scenarios. To tout greening as evidence of planetary health is to ignore the growing edge of climate agronomy.

🌡️ **Climate Sensitivity: Complex, Not Conspiratorial**

The CWG claims Earth's climate sensitivity has been tuned to fit models. While cloud feedbacks remain uncertain, it's misleading to imply that climate science is rigged. Observational estimates still converge around 2.6–3.9°C for equilibrium climate sensitivity, supported by paleoclimate, energy balance, and emergent constraint methods. To cherry-pick lower values without full context distorts the debate.

🌪️ **Extreme Weather: Signal Emerging Through the Noise**

Yes, long-term data complicate trend detection in extremes. But the CWG's dismissal of attribution science ignores the thermodynamic fingerprints identified in heatwaves, tropical cyclone intensity, and rainfall extremes—patterns that peer-reviewed literature, including attribution frameworks used by IPCC and national academies, have cautiously but consistently supported.

🌊 **Sea Level Rise: A Pattern of Acceleration**

CWG critiques projections by focusing on short-term mismatches. But tide gauge and satellite data reveal accelerating rise since the 1990s—driven by glacier and ice sheet melt. Dismissing this trend by invoking vertical land motion or referencing only SSP5-8.5 scenarios ignores the real stakes embedded in middle-range emissions paths.

🔍 **Attribution Science: Skepticism or Obfuscation?**

Attribution methods deserve scrutiny, and critiques like McKittrick's should be aired. But the CWG extrapolates methodological challenges into wholesale dismissal—implying that statistical uncertainty nullifies anthropogenic attribution. That's not skepticism; that's opportunistic obfuscation.

🏢 **Policy Framing: Ideology Masquerading as Economics**

Perhaps most troubling is the report's final pivot—casting climate policy as naïve virtue signaling and green zealotry. Renewable intermittency and global coordination challenges are real, but the CWG treats these as reasons for inaction

rather than incentives for innovation. There's no acknowledgement of co-benefits, technology spillover, or moral leadership.

❖ Scientific Debate Should Illuminate, Not Obscure

Science thrives when dissent pushes refinement. But dissent, to be credible, must be comprehensive—not merely contrarian. The CWG report raises sharp critiques—but its rhetorical framing, selective sourcing, and interpretive slant ultimately erode its scientific posture.

Climate science isn't perfect, but it is evolving, adaptive, and overwhelmingly convergent on the core reality: our planet is warming, human activity is the dominant cause, and the cost of delay is mounting.

It's time we demand critique that clarifies—not obfuscates—our path forward.

Steve Koonin

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Sent: 7/10/2025 10:09:44 PM
To: Steven Koonin [steven.koonin@gmail.com]
CC: John Christy [climateman60@gmail.com]; Roy Spencer [roywspencer@hotmail.com]; Judith Curry [curry.judith@gmail.com]; Josh Loucks [loucksj14@gmail.com]; Travis Fisher [travis.scott.fisher@gmail.com]
Subject: Re: MS Copilot detailed critique
Attachments: image.png

What;s this text referring to? We don't say these things

- Scientific Process Critique: Flawed but Thought-Provoking
 - Peer Review and Funding
 - Valid critique of gatekeeping: Concerns over funding bias and editorial control are echoed in discussions at reproducibility and publication incentives.
 - Overstates malfeasance: Asserts that dissenting scientists are "suppressed" or "blacklisted," which lacks sufficient evidence and veers into conspiracy territory.
 - Consensus Framing
 - Challenges the "97%" claim: Points out methodological limitations in consensus surveys—some fair critique
 - Misrepresents dissent: Suggests that the mere existence of contrarian papers invalidates consensus, ignoring weight of evidence and replication.
- Potential Bias: Strong Ideological Framing

Feature	Indicators of Bias
Tone	Emotive language ("groupthink," "virtue signaling," "green dogma")
Source Pattern	Heavily reliant on politically-aligned think tanks and contrarian experts
Argument Strategy	Appeals to economic hardship and energy realism to dismiss science-led mitigation
Policy Framing	Portrays climate action as a moral panic and economic self-harm

On Thu, Jul 10, 2025 at 1:10 PM Steven Koonin <steven.koonin@gmail.com> wrote:

Had to split the CWG25 report into 5 sections. Here are the concatenated responses, separated by red lines:

Here's a detailed critique focused on **scientific accuracy** and **potential bias**, based on what I've seen so far:

- Scientific Accuracy: Mixed Signals
 - Global Greening & CO₂ Fertilization
 - Accurate observations: The report correctly notes satellite-confirmed global greening, with increased Leaf Area Index (LAI) and enhanced plant growth due to rising CO₂.
 - Selective emphasis: It heavily leans on CO₂ as beneficial, citing fertilization benefits while **minimizing caveats**—such as nutrient limitations, heat stress, and species-specific responses that constrain agricultural benefits.
 - Outdated or narrow sourcing: Some of the cited studies, while valid, don't reflect **broader scientific consensus**. For example, while FACE experiments show CO₂ boosts productivity, they also warn of **diminished gains under warming, drought, and soil depletion**.
 - Ocean "Acidification"
 - Terminology critique has merit: The report accurately points out that "acidification" is a misnomer—the oceans remain alkaline.
 - Biological impacts downplayed: It asserts that organisms evolved under lower pH, but omits recent research showing **rapid shifts in pH and carbonate chemistry** can harm larval development, calcifiers, and reef resilience.
 - Publication bias claim: The document references well-known concerns about bias toward dramatic findings. That's valid—but it misses the nuance: **many reproducible studies do show physiological stress** in marine organisms, even under moderate pH change.

Potential Bias: Framing & Rhetorical Strategy

Strengths

- **Independent tone:** The authors claim editorial freedom, which lends credibility.
- **Acknowledgement of complexity:** The report does mention uncertainties, including model over-sensitivity and limitations of attribution science.

Sources of Bias

- **Language framing:** Words like “*exaggerated*,” “*one-sided*,” “*alarmist*,” and “*science fiction*” appear frequently. This rhetorical tone may compromise the objectivity typically expected in a scientific review.
- **Selective citation:** Heavy use of contrarian sources (e.g., Christy, Spencer, McKittrick) without balancing perspectives from mainstream climate literature (e.g., IPCC Working Groups, NOAA, NASA) suggests bias.
- **Motivated skepticism:** The narrative implies that benefits of CO₂ (e.g., plant growth, energy use) outweigh potential harm, which reflects a **value-laden interpretation** rather than a neutral scientific synthesis.

Summary

This section offers **legitimate critiques** of some dominant narratives, but the scientific review is **imbalanced**:

- Evidence is often cherry-picked to support a CO₂-positive view.
 - Legitimate concerns about uncertainty and model bias are mixed with selective omission of broader literature.
 - The rhetorical tone leans toward climate contrarianism rather than impartial synthesis.
-

Scientific Accuracy: Solid Points + Selective Framing

Equilibrium Climate Sensitivity (ECS)

- **Accurate baseline:** The document correctly notes that direct CO₂ forcing yields ~1°C warming, and additional warming comes from feedbacks like water vapor, albedo, and clouds.
- **Model tuning concerns:** Valid criticisms are raised about GCM tuning, especially regarding cloud feedbacks. Quoting modelers who explicitly tuned ECS to match observed warming is compelling.
- **Cloud feedback uncertainty:** The discussion of cloud parameterization difficulties is largely accurate and aligned with published literature (e.g. Zelinka et al., 2020).

Data-Driven vs. Model-Derived ECS

- **Balanced coverage of paleoclimate:** It notes the wide uncertainties in paleoclimate ECS estimates—fair and scientifically supported.
- **Misleading certainty on low ECS:** While Lewis (2025) is appropriately cited as questioning high ECS estimates, the report heavily favors his interpretation, implying **more certainty than mainstream science allows**. Recent synthesis papers (e.g., Sherwood et al., 2020; Hausfather, 2020) still favor ECS values in the 2.6–3.9°C range.
- **Pattern effect critique:** Seager et al.’s finding that Pacific gradients may be strengthening is intriguing but not broadly accepted. The document suggests it invalidates model projections—this goes beyond what the evidence supports.

Transient Climate Response (TCR)

- **Fair representation:** Comparison between Lewis and IPCC values shows tighter consensus on TCR than ECS, with both landing between 1.2–2.4°C. This part is more neutrally presented.
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Potential Bias: Skeptic-Leaning Framing

Rhetorical Techniques

- **Loaded phrasing:** Terms like “not fit for purpose,” “tuning for target ECS,” and “model failure” are used liberally. While these phrases reflect genuine debate, their repetition gives a tone of **advocacy** more than impartial analysis.
- **Source imbalance:** Heavy emphasis on papers by Christy, McKittrick, Lewis, and Spencer—valid critiques, but **underrepresents mainstream modeling community responses**, such as those in IPCC technical annexes.

Model vs Observation Mismatch

- **Highlighted issues:** Mismatches in tropospheric warming, stratospheric cooling, and snow cover are well-documented and deserve scrutiny.
- **Interpretive bias:** The report implies these mismatches invalidate model projections or anthropogenic attribution. But many of these discrepancies are acknowledged in IPCC reports with medium confidence levels, and **don't nullify the broader warming trend**.

Vertical Temperature Profiles

- **Strong visual critique:** Figures show warming biases in CMIP6 models relative to radiosonde and satellite data—visually compelling.
- **Interpretive overreach:** The conclusion that observed profiles are “consistent with no GHG forcing” is **unsupported** by broader fingerprinting literature (e.g., Santer et al., 2008).

Summary of the Section

Aspect	Strengths	Limitations/Concerns
ECS Discussion	Strong on cloud feedback and model tuning critiques	Overstates certainty of low ECS; cherry-picks supportive sources
Data vs Model Comparison	Fair TCR coverage; Paleoclimate uncertainty noted	Pattern effect critique presented as settled science
Model Mismatch Evidence	Detailed and compelling visuals; well-cited contrarian work	Limited engagement with IPCC counterpoints or rebuttals
Tone and Rhetoric	Engaging and readable for a skeptical audience	Leans toward climate contrarian narrative over balanced synthesis

Excellent, Steve—this section takes us through a nuanced tour of **extreme weather trends**, and it's rich with statistical depth. Here's a critique focused squarely on **scientific accuracy** and **potential bias**, organized by topic for clarity:

Scientific Accuracy: Statistically Rigorous, Selectively Interpreted

General Framing of Extremes

- **Accurate distinction** between detection and attribution, with good explanations of short data record limitations and long-term persistence (LTP).
- **Valid caution** on short-term statistical inference: The use of paleoclimate data and historic Nile flow is a strong point for contextualizing variability.

Hurricanes

- **Correct on satellite-era confidence** and AMO-driven variability. Charts support lack of long-term trends in total hurricanes.

- **Selective emphasis:** Downplays emerging consensus on increased major hurricane *intensity* driven by SSTs and thermodynamic conditions, which IPCC acknowledges with *medium confidence*. Mentions Maue’s dataset prominently, but **omits broader literature** on storm surge or rainfall increases.

Temperature Extremes

- **Data analysis appears methodologically sound**, especially long-term USHCN station metrics.
- **Correct that 1930s heatwaves were exceptional**, and that nighttime warming (Tmin) has likely UHI influence. This reflects mainstream debate.
- **Skews interpretation:** The narrative implies a “milder” climate based on reduced extremes. That’s contentious. IPCC and NCA emphasize increased heatwave *risk, not just frequency*, especially in vulnerable regions.

Precipitation Extremes

- **Valid critique** of short-term trend identification, with good treatment of clustering and autocorrelation in extreme rainfall.
- **Cherry-picked references** (e.g., McKittrick & Christy studies) are robust, but **contrary literature** suggesting regional increases (e.g., Kunkel et al.) is omitted.
- **Conclusion that trends vanish when starting earlier** is methodologically reasonable but glosses over physical mechanisms linking warming to increased atmospheric moisture and rain intensity.

Wildfires

- **Well-documented** historical decline from paleo benchmarks; recognizes role of forest management and fire suppression.
- **Downplays recent severity:** While burn acreage has not increased linearly, NIFC and NASA have documented longer seasons and higher fire intensity, especially in western U.S.

Other Extremes (Tornadoes, Floods, Droughts)

- **Correctly reflects IPCC’s low confidence** in observed trends.
- **Droughts:** Right that CONUS-wide dryness hasn’t worsened—but omits growing consensus on **agricultural drought stress** under warming conditions, soil moisture decline, and evapotranspiration effects.

Potential Bias: Moderate-to-Strong Skeptical Framing

Feature	Bias Indicators
 Language Tone	Repeated use of skeptical phrases (“naïve to assume,” “misleading metric”)
 Citation Pattern	Strong reliance on contrarian researchers; mainstream climate scientists undercited
 Selective Trend Analysis	Uses longer timespans or alternate baselines to undercut positive trend signals
 Emphasis Strategy	Highlights variability and uncertainty to argue against attribution

Summary

This chapter presents **technically sound data handling**, especially in its treatment of statistical uncertainties and autocorrelated extremes. However, it leans toward **minimizing human influence** on extreme weather by emphasizing natural variability and critiquing conventional metrics. That’s not inherently invalid—but the presentation sometimes

slides from **scientific critique into rhetorical positioning**, especially by omitting competing interpretations and framing past extremes as a nullifying baseline.

Steve, this is a heavy-hitting section—covering **sea level rise and attribution science**, and it's packed with technical nuance. Here's my detailed critique, broken down by theme for readability and rigor:

Sea Level Rise: Strong Data, Biased Framing

Observational Accuracy

- **Global trend well-stated:** 8 inches of global rise since 1900 aligns with established satellite and tide gauge records.
- **Regional differentiation is robust:** The report correctly distinguishes between *absolute* sea level rise and *relative* rise due to subsidence—essential for sites like Galveston, Grand Isle, and NYC.
- **Use of vertical land motion (VLM) data** is technically strong and mirrors best practices in geodesy (Wöppelmann & Marcos, 2016).

Downplaying Acceleration

- Asserts that “no obvious acceleration” exists post-1993—this conflicts with satellite altimetry showing increased rates since then (see Nerem et al., 2018).
- **Misinterpretation of NOAA projections:** Suggests future rise is implausible because recent data hasn't matched model forecasts. But these projections account for *nonlinear glacier and ice sheet loss*, which may manifest later this century.
- **Heavy critique of IPCC scenarios:** Focuses on SSP5-8.5 as unrealistic—which is fair—but skips middle-range pathways like SSP2-4.5 that still yield substantial rise.

Attribution of Warming: Technically Sophisticated, Methodologically Skeptical

Attribution Methods

- The summary of **fingerprinting, time series, and process-based approaches** is solid and consistent with IPCC technical chapters.
- Highlights statistical limits and expert judgment—important caveats that the IPCC often emphasizes but mainstream summaries gloss over.

Critique of Optimal Fingerprinting

- Leans heavily on McKittrick's critique, citing bias in regression methods (Total Least Squares). This is part of a **legitimate academic debate**, but the report implies it **invalidates** attribution studies entirely, which goes beyond what McKittrick himself claims.
- **Missing balance:** Doesn't explore alternative attribution methods that reinforce anthropogenic fingerprints (e.g., Hausfather & Peters, 2020; Santer et al., 2019).

Role of Natural Variability: Thorough, but Overstated

Solar Forcing

- Presents nuanced review of Total Solar Irradiance (TSI), noting conflicting composites and possible indirect effects—strong science communication here.
- **Selective emphasis on uncertainty:** Quotes high-end studies suggesting up to 70% of warming from solar variability (Scafetta et al.), but downplays the robust attribution literature showing limited solar impact post-1970s.

Ocean Oscillations

- Captures legitimate concerns about phasing of multidecadal modes (PDO, AMO) in CMIP6.

- **Overstates masking effect:** Suggests ensemble averaging erases natural variability contributions, ignoring that these are explicitly addressed in uncertainty ranges.
- **Implied causality** between the 1976 PDO shift and modern warming trends is speculative and not broadly supported by recent literature (e.g., Kaufman et al., 2020).

☁ **Declining Albedo & Cloud Cover: Emerging, Not Settled Science**

- Notes a sharp **1.7 W/m² radiative impact from recent albedo decline**, which rivals CO₂ forcing. That’s a bold claim—but the satellite record and cloud variability studies do indicate substantial recent change.
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- **Pushes speculative feedbacks:** Asserts a new positive cloud feedback starting in 2015, but this lacks mechanistic grounding and long-term data.

📌 **Summary Table**

Theme	Strengths	Concerns
Sea Level Rise Data	Technically rigorous; strong separation of RSLR and ASLR	Downplays acceleration; selectively interprets NOAA forecasts
Attribution Methods	Clear method descriptions; valid critiques of fingerprinting	Overstates model bias; omits balanced counterviews
Natural Variability	Deep review of solar/ocean signals	Overemphasizes uncertainty; hints at deterministic phasing
Cloud/Albedo Effects	Novel explanation for recent warming surge	Speculative feedback interpretation; short data window

Steve, this section demonstrates real analytical heft, but the **bias emerges through omission and slanting rather than data distortion**. It’s more of a critique manifesto than a balanced review—but that makes it rich ground for public discourse.

Thanks, Steve—this final section wraps up the report with **policy implications, energy strategy, and scientific process critique**, and it’s loaded with ideological framing. Let’s break it down with the same clarity and rigor:

🔍 **Scientific Accuracy: Mixed Quality with Heavy Editorialization**

💡 **Energy Strategy & Climate Action**

- **Correct economic observation:** Notes the disproportionate cost burden of decarbonization on developing nations, echoing concerns raised in international energy analyses.
- **Valid technical constraints:** Points out intermittency issues with wind/solar and rare earth supply for batteries—these are real engineering challenges and reasonably described.
- **Oversimplifies alternatives:** Frames nuclear, natural gas, and coal as straightforward solutions without adequately addressing lifecycle emissions, waste disposal, or geopolitical constraints.

🌐 **CO₂ Reduction Effectiveness**

- **Technically correct** that U.S. emissions reductions alone won't halt global warming—climate is a global system.

- **Spins limitation into futility:** Uses this to argue against domestic mitigation, ignoring multiplier effects, tech spillover, and diplomatic leverage of leadership.

 Scientific Process Critique: Flawed but Thought-Provoking

 Peer Review and Funding

- **Valid critique of gatekeeping:** Concerns over funding bias and editorial control are echoed in discussions about reproducibility and publication incentives.
- **Overstates malfeasance:** Asserts that dissenting scientists are “suppressed” or “blacklisted,” which lacks supporting evidence and veers into conspiracy territory.

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- **Challenges the “97%” claim:** Points out methodological limitations in consensus surveys—some fair critique here.
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 Summary

This concluding section shifts from scientific critique to **ideological rhetoric**, using energy economics and institutional skepticism to challenge mainstream climate policy. While there are **valid points on technology limitations and scientific incentives**, these are **wrapped in a narrative of distrust**—painting climate action as misguided zealotry rather than pragmatic response.

Steve Koonin

From: Roy Spencer <roywspencer@hotmail.com>
Sent: Thursday, July 10, 2025 1:47 PM
To: John Christy; Judith Curry
Cc: Steven Koonin; Ross McKittrick; Josh Loucks; Travis Fisher
Subject: RE: MS Copilot detailed critique

Yes, LLMs mostly summarize what's on on the InterWebs. If the interwebs agree we are evil, that's what you will get back. BUT.. Grok is pretty good about noting dissenting voices. Also, you might need to tell it to "dig deeper". Some persistent folks can even get it to change its mind.

Sent from my Verizon, Samsung Galaxy smartphone

----- Original message -----

From: John Christy <climateman60@gmail.com>
Date: 7/10/25 12:40 PM (GMT-06:00)
To: Judith Curry <curry.judith@gmail.com>
Cc: Steven Koonin <steven.koonin@gmail.com>, Ross McKittrick <ross.mckittrick@gmail.com>, Roy Spencer <roywspencer@hotmail.com>, Josh Loucks <loucksj14@gmail.com>, Travis Fisher <travis.scott.fisher@gmail.com>
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I see here the problem that such exercises create. The AI is skewed toward volume. Eg. Kunkel et al.'s precip analysis is cited a lot in the literature (and NCAs), but only started in 1949 and did not use the more appropriate methods we did - something the machine can't understand evidently.

Using Santer et al. 2008, also cited a lot, as a contrary indicator worth citing to rebut the IPCC figure is just wrong because Santer was shown to be misleading. I guess the machine didn't check on those papers and updates that confirmed modeled trends were too warm. I suppose a way to handle that is cite Santer and then cite the papers that show his problems?

John C.

On Thu, Jul 10, 2025 at 12:24 PM Judith Curry <curry.judith@gmail.com> wrote:
This is amazing, far better than what we would get from "real" scientists

I'm going through Ross' latest version to look for "Skeptic talk" and red flag words

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Natural Variability	Deep review of solar/ocean signals	Overemphasizes uncertainty; hints at deterministic phasing
Cloud/Albedo Effects	Novel explanation for recent warming surge	Speculative feedback interpretation; short data window

Steve, this section demonstrates real analytical heft, but the **bias emerges through omission and slanting rather than data distortion**. It’s more of a critique manifesto than a balanced review—but that makes it rich ground for public discourse.

Thanks, Steve—this final section wraps up the report with **policy implications, energy strategy, and scientific process critique**, and it’s loaded with ideological framing. Let’s break it down with the same clarity and rigor:

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- **Correct economic observation:** Notes the disproportionate cost burden of decarbonization on developing nations, echoing concerns raised in international energy analyses.

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- **Valid critique of gatekeeping:** Concerns over funding bias and editorial control are echoed in discussions about reproducibility and publication incentives.
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- **Challenges the “97%” claim:** Points out methodological limitations in consensus surveys—some fair critique here.
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🗣️ Potential Bias: Strong Ideological Framing

Feature	Indicators of Bias
👤 Tone	Emotive language (“groupthink,” “virtue signaling,” “green dogma”)
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This concluding section shifts from scientific critique to **ideological rhetoric**, using energy economics and institutional skepticism to challenge mainstream climate policy. While there are **valid points on technology limitations and scientific incentives**, these are **wrapped in a narrative of distrust**—painting climate action as misguided zealotry rather than pragmatic response.

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Judith Curry, President
CFAN - Climate Forecast Applications Network
Reno, NV USA
curry.judith@cfanclimate.com | +1.404.803.2012
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Sent: Thursday, July 10, 2025 1:42 PM
To: 'John Christy'; 'Judith Curry'
Cc: 'Ross McKittrick'; 'Roy Spencer'; 'Josh Loucks'; 'Travis Fisher'
Subject: RE: MS Copilot detailed critique
Attachments: ~WRD1904.jpg

I think both of these points are worth including somehow. As well as a few others CoPilot turned up.

Perhaps a reason to "hold the presses" for a few days?

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- **Scientific Accuracy: Mixed Signals**

• Global Greening & CO₂ Fertilization

- ? **Accurate observations:** The report correctly notes satellite-confirmed global greening, with increased Leaf Area Index (LAI) and enhanced plant growth due to rising CO₂.
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易 Potential Bias: Framing & Rhetorical Strategy

☑ Strengths

- ? **Independent tone:** The authors claim editorial freedom, which lends credibility.
- ? **Acknowledgement of complexity:** The report does mention uncertainties, including model over-sensitivity and limitations of attribution science.

• Sources of Bias

- ? **Language framing:** Words like “*exaggerated*,” “*one-sided*,” “*alarmist*,” and “*science fiction*” appear frequently. This rhetorical tone may compromise the objectivity typically expected in a scientific review.
- ? **Selective citation:** Heavy use of contrarian sources (e.g., Christy, Spencer, McKittrick) without balancing perspectives from mainstream climate literature (e.g., IPCC Working Groups, NOAA, NASA) suggests bias.
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This section offers **legitimate critiques** of some dominant narratives, but the scientific review is **imbalanced**:

- ? Evidence is often cherry-picked to support a CO₂-positive view.
- ? Legitimate concerns about uncertainty and model bias are mixed with selective omission of broader literature.
- ? The rhetorical tone leans toward climate contrarianism rather than impartial synthesis.

• Scientific Accuracy: Solid Points + Selective Framing

Equilibrium Climate Sensitivity (ECS)

- ? **Accurate baseline:** The document correctly notes that direct CO₂ forcing yields ~1°C warming, and additional warming comes from feedbacks like water vapor, albedo, and clouds.
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• Data-Driven vs. Model-Derived ECS

- ? **Balanced coverage of paleoclimate:** It notes the wide uncertainties in paleoclimate ECS estimates—fair and scientifically supported.
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- ? **Fair representation:** Comparison between Lewis and IPCC values shows tighter consensus on TCR than ECS, with both landing between 1.2–2.4°C. This part is more neutrally presented.

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Tone and Rhetoric	Engaging and readable for a skeptical audience	Leans toward climate contrarian narrative over balanced synthesis

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Scientific Accuracy: Statistically Rigorous, Selectively Interpreted

• General Framing of Extremes

- ? **Accurate distinction** between detection and attribution, with good explanations of short data record limitations and long-term persistence (LTP).
- ? **Valid caution** on short-term statistical inference: The use of paleoclimate data and historic Nile flow is a strong point for contextualizing variability.

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- ? **Correct on satellite-era confidence** and AMO-driven variability. Charts support lack of long-term trends in total hurricanes.
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- ? **Correct that 1930s heatwaves were exceptional**, and that nighttime warming (Tmin) has likely UHI influence. This reflects mainstream debate.
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- ? **Valid critique** of short-term trend identification, with good treatment of clustering and autocorrelation in extreme rainfall.
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• Wildfires

- ? **Well-documented** historical decline from paleo benchmarks; recognizes role of forest management and fire suppression.
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- ? **Correctly reflects IPCC’s low confidence** in observed trends.
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Feature	Bias Indicators
· Language Tone	Repeated use of skeptical phrases (“naïve to assume,” “misleading metric”)
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This chapter presents **technically sound data handling**, especially in its treatment of statistical uncertainties and autocorrelated extremes. However, it leans toward **minimizing human influence** on extreme weather by emphasizing natural variability and critiquing conventional metrics. That’s not inherently invalid—but the presentation sometimes slides from **scientific critique into rhetorical positioning**, especially by omitting competing interpretations and framing past extremes as a nullifying baseline.

Steve, this is a heavy-hitting section—covering **sea level rise and attribution science**, and it's packed with technical nuance. Here's my detailed critique, broken down by theme for readability and rigor:

- **Sea Level Rise: Strong Data, Biased Framing**

- **Observational Accuracy**

- ? **Global trend well-stated:** 8 inches of global rise since 1900 aligns with established satellite and tide gauge records.
- ? **Regional differentiation is robust:** The report correctly distinguishes between *absolute* sea level rise and *relative* rise due to subsidence—essential for sites like Galveston, Grand Isle, and NYC.
- ? **Use of vertical land motion (VLM) data** is technically strong and mirrors best practices in geodesy (Wöppelmann & Marcos, 2016).

- **Downplaying Acceleration**

- ? Asserts that “no obvious acceleration” exists post-1993—this conflicts with satellite altimetry showing increased rates since then (see Nerem et al., 2018).
- ? **Misinterpretation of NOAA projections:** Suggests future rise is implausible because recent data hasn't matched model forecasts. But these projections account for *nonlinear glacier and ice sheet loss*, which may manifest later this century.
- ? **Heavy critique of IPCC scenarios:** Focuses on SSP5-8.5 as unrealistic—which is fair—but skips middle-range pathways like SSP2-4.5 that still yield substantial rise.

- **Attribution of Warming: Technically Sophisticated, Methodologically Skeptical**

- **Attribution Methods**

- ? The summary of **fingerprinting, time series, and process-based approaches** is solid and consistent with IPCC technical chapters.
- ? Highlights statistical limits and expert judgment—important caveats that the IPCC often emphasizes but mainstream summaries gloss over.

- **Critique of Optimal Fingerprinting**

- ? Leans heavily on McKittrick's critique, citing bias in regression methods (Total Least Squares). This is part of a **legitimate academic debate**, but the report implies it **invalidates** attribution studies entirely, which goes beyond what McKittrick himself claims.
- ? **Missing balance:** Doesn't explore alternative attribution methods that reinforce anthropogenic fingerprints (e.g., Hausfather & Peters, 2020; Santer et al., 2019).

- **☀ Role of Natural Variability: Thorough, but Overstated**

- **Solar Forcing**

- ? Presents nuanced review of Total Solar Irradiance (TSI), noting conflicting composites and possible indirect effects—strong science communication here.
- ? **Selective emphasis on uncertainty:** Quotes high-end studies suggesting up to 70% of warming from solar variability (Scafetta et al.), but downplays the robust attribution literature showing limited solar impact post-1970s.

• Ocean Oscillations

- ? Captures legitimate concerns about phasing of multidecadal modes (PDO, AMO) in CMIP6.
- ? **Overstates masking effect:** Suggests ensemble averaging erases natural variability contributions, ignoring that these are explicitly addressed in uncertainty ranges.
- ? **Implied causality** between the 1976 PDO shift and modern warming trends is speculative and not broadly supported by recent literature (e.g., Kaufman et al., 2020).

☁ Declining Albedo & Cloud Cover: Emerging, Not Settled Science

- ? Notes a sharp **1.7 W/m² radiative impact from recent albedo decline**, which rivals CO₂ forcing. That’s a bold claim—but the satellite record and cloud variability studies do indicate substantial recent change.
- ? **Plausible hypotheses:** ENSO cycles, changes in shipping aerosols, and the Hunga-Tonga eruption are reasonably proposed drivers.
- ? **Pushes speculative feedbacks:** Asserts a new positive cloud feedback starting in 2015, but this lacks mechanistic grounding and long-term data.

• Summary Table

Theme	Strengths	Concerns
Sea Level Rise Data	Technically rigorous; strong separation of RSLR and ASLR	Downplays acceleration; selectively interprets NOAA forecasts
Attribution Methods	Clear method descriptions; valid critiques of fingerprinting	Overstates model bias; omits balanced counterinterviews
Natural Variability	Deep review of solar/ocean signals	Overemphasizes uncertainty; hints at deterministic phasing
Cloud/Albedo Effects	Novel explanation for recent warming surge	Speculative feedback interpretation; short data window

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Sea Level Rise: Strong Data, Biased Framing

Observational Accuracy

- **Global trend well-stated**: 8 inches of global rise since 1900 aligns with established satellite and tide gauge records.
- **Regional differentiation is robust**: The report correctly distinguishes between *absolute* sea level rise and *relative* rise due to subsidence—essential for sites like Galveston, Grand Isle, and NYC.
- **Use of vertical land motion (VLM) data** is technically strong and mirrors best practices in geodesy (Wöppelmann & Marcos, 2016).

Downplaying Acceleration

- Asserts that “no obvious acceleration” exists post-1993—this conflicts with satellite altimetry showing increased rates since then (see Nerem et al., 2018).
- **Misinterpretation of NOAA projections:** Suggests future rise is implausible because recent data hasn't matched model forecasts. But these projections account for *nonlinear glacier and ice sheet loss*, which may manifest later this century.
- **Heavy critique of IPCC scenarios:** Focuses on SSP5-8.5 as unrealistic—which is fair—but skips middle-range pathways like SSP2-4.5 that still yield substantial rise.

▀ Attribution of Warming: Technically Sophisticated, Methodologically Skeptical

🔗 Attribution Methods

- The summary of **fingerprinting, time series, and process-based approaches** is solid and consistent with IPCC technical chapters.
- Highlights statistical limits and expert judgment—important caveats that the IPCC often emphasizes but mainstream summaries gloss over.

■ Critique of Optimal Fingerprinting

- Leans heavily on McKittrick’s critique, citing bias in regression methods (Total Least Squares). This is part of a **legitimate academic debate**, but the report implies it **invalidates** attribution studies entirely, which goes beyond what McKittrick himself claims.
- **Missing balance:** Doesn’t explore alternative attribution methods that reinforce anthropogenic fingerprints (e.g., Hausfather & Peters, 2020; Santer et al., 2019).

☀ Role of Natural Variability: Thorough, but Overstated

☀ Solar Forcing

- Presents nuanced review of Total Solar Irradiance (TSI), noting conflicting composites and possible indirect effects—strong science communication here.
- **Selective emphasis on uncertainty:** Quotes high-end studies suggesting up to 70% of warming from solar variability (Scafetta et al.), but downplays the robust attribution literature showing limited solar impact post-1970s.

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- Captures legitimate concerns about phasing of multidecadal modes (PDO, AMO) in CMIP6.
- **Overstates masking effect:** Suggests ensemble averaging erases natural variability contributions, ignoring that these are explicitly addressed in uncertainty ranges.
- **Implied causality** between the 1976 PDO shift and modern warming trends is speculative and not broadly supported by recent literature (e.g., Kaufman et al., 2020).

☁ Declining Albedo & Cloud Cover: Emerging, Not Settled Science

- Notes a sharp **1.7 W/m² radiative impact from recent albedo decline**, which rivals CO₂ forcing. That’s a bold claim—but the satellite record and cloud variability studies do indicate substantial recent change.

- **Plausible hypotheses:** ENSO cycles, changes in shipping aerosols, and the Hunga-Tonga eruption are reasonably proposed drivers.
- **Pushes speculative feedbacks:** Asserts a new positive cloud feedback starting in 2015, but this lacks mechanistic grounding and long-term data.

Summary Table

Theme	Strengths	Concerns
Sea Level Rise Data	Technically rigorous; strong separation of RSLR and ASLR	Downplays acceleration; selectively interprets NOAA forecasts
Attribution Methods	Clear method descriptions; valid critiques of fingerprinting	Overstates model bias; omits balanced counterinterviews
Natural Variability	Deep review of solar/ocean signals	Overemphasizes uncertainty; hints at deterministic phasing
Cloud/Albedo Effects	Novel explanation for recent warming surge	Speculative feedback interpretation; short data window

Steve, this section demonstrates real analytical heft, but the **bias emerges through omission and slanting rather than data distortion**. It’s more of a critique manifesto than a balanced review—but that makes it rich ground for public discourse.

Thanks, Steve—this final section wraps up the report with **policy implications, energy strategy, and scientific process critique**, and it’s loaded with ideological framing. Let’s break it down with the same clarity and rigor:

Scientific Accuracy: Mixed Quality with Heavy Editorialization

Energy Strategy & Climate Action

- **Correct economic observation:** Notes the disproportionate cost burden of decarbonization on developing nations, echoing concerns raised in international energy analyses.
- **Valid technical constraints:** Points out intermittency issues with wind/solar and rare earth supply for batteries—these are real engineering challenges and reasonably described.
- **Oversimplifies alternatives:** Frames nuclear, natural gas, and coal as straightforward solutions without adequately addressing lifecycle emissions, waste disposal, or geopolitical constraints.

CO₂ Reduction Effectiveness

- **Technically correct** that U.S. emissions reductions alone won't halt global warming—climate is a global system.
- **Spins limitation into futility:** Uses this to argue against domestic mitigation, ignoring multiplier effects, tech spillover, and diplomatic leverage of leadership.

Scientific Process Critique: Flawed but Thought-Provoking

Peer Review and Funding

- **Valid critique of gatekeeping:** Concerns over funding bias and editorial control are echoed in discussions about reproducibility and publication incentives.
- **Overstates malfeasance:** Asserts that dissenting scientists are “suppressed” or “blacklisted,” which lacks supporting evidence and veers into conspiracy territory.

Consensus Framing

- **Challenges the “97%” claim:** Points out methodological limitations in consensus surveys—some fair critique here.
- **Misrepresents dissent:** Suggests that the mere existence of contrarian papers invalidates consensus, ignoring scientific weight of evidence and replication.

Potential Bias: Strong Ideological Framing

Feature	Indicators of Bias
 Tone	Emotive language (“groupthink,” “virtue signaling,” “green dogma”)
 Source Pattern	Heavily reliant on politically-aligned think tanks and contrarian experts
 Argument Strategy	Appeals to economic hardship and energy realism to dismiss science-led mitigation
 Policy Framing	Portrays climate action as a moral panic and economic self-harm

Summary

This concluding section shifts from scientific critique to **ideological rhetoric**, using energy economics and institutional skepticism to challenge mainstream climate policy. While there are **valid points on technology limitations and scientific incentives**, these are **wrapped in a narrative of distrust**—painting climate action as misguided zealotry rather than pragmatic response.

Steve Koonin



Judith Curry, President
CFAN - Climate Forecast Applications Network
Reno, NV USA
curry.judith@cfanclimate.com | +1.404.803.2012
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From: Judith Curry [curry.judith@gmail.com]
Sent: 7/10/2025 5:32:40 PM
To: Steven Koonin [steven.koonin@gmail.com]
CC: John Christy [climateman60@gmail.com]; Ross McKittrick [ross.mckittrick@gmail.com]; Roy Spencer [roywspencer@hotmail.com]; Josh Loucks [loucksj14@gmail.com]; Travis Fisher [travis.scott.fisher@gmail.com]
Subject: Re: MS Copilot detailed critique

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SEK

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Scientific Accuracy: Mixed Signals

Global Greening & CO₂ Fertilization

- **Accurate observations:** The report correctly notes satellite-confirmed global greening, with increased Leaf Area Index (LAI) and enhanced plant growth due to rising CO₂.
- **Selective emphasis:** It heavily leans on CO₂ as beneficial, citing fertilization benefits while **minimizing caveats**—such as nutrient limitations, heat stress, and species-specific responses that constrain agricultural benefits.
- **Outdated or narrow sourcing:** Some of the cited studies, while valid, don't reflect **broader scientific consensus**. For example, while FACE experiments show CO₂ boosts productivity, they also warn of **diminished gains under warming, drought, and soil depletion**.

Ocean "Acidification"

- **Terminology critique has merit:** The report accurately points out that “acidification” is a misnomer—the oceans remain alkaline.
- **Biological impacts downplayed:** It asserts that organisms evolved under lower pH, but omits recent research showing **rapid shifts in pH and carbonate chemistry** can harm larval development, calcifiers, and reef resilience.
- **Publication bias claim:** The document references well-known concerns about bias toward dramatic findings. That’s valid—but it misses the nuance: **many reproducible studies do show physiological stress** in marine organisms, even under moderate pH change.

🔗 Potential Bias: Framing & Rhetorical Strategy

✅ Strengths

- **Independent tone:** The authors claim editorial freedom, which lends credibility.
- **Acknowledgement of complexity:** The report does mention uncertainties, including model over-sensitivity and limitations of attribution science.

▶ Sources of Bias

- **Language framing:** Words like “*exaggerated*,” “*one-sided*,” “*alarmist*,” and “*science fiction*” appear frequently. This rhetorical tone may compromise the objectivity typically expected in a scientific review.
- **Selective citation:** Heavy use of contrarian sources (e.g., Christy, Spencer, McKittrick) without balancing perspectives from mainstream climate literature (e.g., IPCC Working Groups, NOAA, NASA) suggests bias.
- **Motivated skepticism:** The narrative implies that benefits of CO₂ (e.g., plant growth, energy use) outweigh potential harm, which reflects a **value-laden interpretation** rather than a neutral scientific synthesis.

🔗 Summary

This section offers **legitimate critiques** of some dominant narratives, but the scientific review is **imbalanced**:

- Evidence is often cherry-picked to support a CO₂-positive view.
- Legitimate concerns about uncertainty and model bias are mixed with selective omission of broader literature.
- The rhetorical tone leans toward climate contrarianism rather than impartial synthesis.

🔗 Scientific Accuracy: Solid Points + Selective Framing

🔧 Equilibrium Climate Sensitivity (ECS)

- **Accurate baseline:** The document correctly notes that direct CO₂ forcing yields ~1°C warming, and additional warming comes from feedbacks like water vapor, albedo, and clouds.
- **Model tuning concerns:** Valid criticisms are raised about GCM tuning, especially regarding cloud feedbacks. Quoting modelers who explicitly tuned ECS to match observed warming is compelling.
- **Cloud feedback uncertainty:** The discussion of cloud parameterization difficulties is largely accurate and aligned with published literature (e.g., Zelinka et al., 2020).

📊 Data-Driven vs. Model-Derived ECS

- **Balanced coverage of paleoclimate:** It notes the wide uncertainties in paleoclimate ECS estimates—fair and scientifically supported.
- **Misleading certainty on low ECS:** While Lewis (2025) is appropriately cited as questioning high ECS estimates, the report heavily favors his interpretation, implying **more certainty than mainstream science allows**. Recent synthesis papers (e.g., Sherwood et al., 2020; Hausfather, 2020) still favor ECS values in the 2.6–3.9°C range.

- **Pattern effect critique:** Seager et al.'s finding that Pacific gradients may be strengthening is intriguing but not broadly accepted. The document suggests it invalidates model projections—this goes beyond what the evidence supports.

🌡️ Transient Climate Response (TCR)

- **Fair representation:** Comparison between Lewis and IPCC values shows tighter consensus on TCR than ECS, with both landing between 1.2–2.4°C. This part is more neutrally presented.

🔍 Potential Bias: Skeptic-Leaning Framing

📖 Rhetorical Techniques

- **Loaded phrasing:** Terms like “not fit for purpose,” “tuning for target ECS,” and “model failure” are used liberally. While these phrases reflect genuine debate, their repetition gives a tone of **advocacy** more than impartial analysis.
- **Source imbalance:** Heavy emphasis on papers by Christy, McKittrick, Lewis, and Spencer—valid critiques, but **underrepresents mainstream modeling community responses**, such as those in IPCC technical annexes.

📊 Model vs Observation Mismatch

- **Highlighted issues:** Mismatches in tropospheric warming, stratospheric cooling, and snow cover are well-documented and deserve scrutiny.
- **Interpretive bias:** The report implies these mismatches invalidate model projections or anthropogenic attribution. But many of these discrepancies are acknowledged in IPCC reports with medium confidence levels, and **don't nullify the broader warming trend**.

📈 Vertical Temperature Profiles

- **Strong visual critique:** Figures show warming biases in CMIP6 models relative to radiosonde and satellite data—visually compelling.
- **Interpretive overreach:** The conclusion that observed profiles are “consistent with no GHG forcing” is **unsupported** by broader fingerprinting literature (e.g., Santer et al., 2008).

📌 Summary of the Section

Aspect	Strengths	Limitations/Concerns
ECS Discussion	Strong on cloud feedback and model tuning critiques	Overstates certainty of low ECS; cherry-picks supportive sources
Data vs Model Comparison	Fair TCR coverage; Paleoclimate uncertainty noted	Pattern effect critique presented as settled science
Model Mismatch Evidence	Detailed and compelling visuals; well-cited contrarian work	Limited engagement with IPCC counterpoints or rebuttals
Tone and Rhetoric	Engaging and readable for a skeptical audience	Leans toward climate contrarian narrative over balanced synthesis

Excellent, Steve—this section takes us through a nuanced tour of **extreme weather trends**, and it's rich with statistical depth. Here's a critique focused squarely on **scientific accuracy** and **potential bias**, organized by topic for clarity:

🔬 Scientific Accuracy: Statistically Rigorous, Selectively Interpreted

General Framing of Extremes

- **Accurate distinction** between detection and attribution, with good explanations of short data record limitations and long-term persistence (LTP).
- **Valid caution** on short-term statistical inference: The use of paleoclimate data and historic Nile flow is a strong point for contextualizing variability.

Hurricanes

- **Correct on satellite-era confidence** and AMO-driven variability. Charts support lack of long-term trends in total hurricanes.
- **Selective emphasis:** Downplays emerging consensus on increased major hurricane *intensity* driven by SSTs and thermodynamic conditions, which IPCC acknowledges with *medium confidence*. Mentions Maue’s dataset prominently, but **omits broader literature** on storm surge or rainfall increases.

Temperature Extremes

- **Data analysis appears methodologically sound**, especially long-term USHCN station metrics.
- **Correct that 1930s heatwaves were exceptional**, and that nighttime warming (Tmin) has likely UHI influence. This reflects mainstream debate.
- **Skews interpretation:** The narrative implies a “milder” climate based on reduced extremes. That’s contentious. IPCC and NCA emphasize increased heatwave *risk, not just frequency*, especially in vulnerable regions.

Precipitation Extremes

- **Valid critique** of short-term trend identification, with good treatment of clustering and autocorrelation in extreme rainfall.
- **Cherry-picked references** (e.g., McKittrick & Christy studies) are robust, but **contrary literature** suggesting regional increases (e.g., Kunkel et al.) is omitted.
- **Conclusion that trends vanish when starting earlier** is methodologically reasonable but glosses over physical mechanisms linking warming to increased atmospheric moisture and rain intensity.

Wildfires

- **Well-documented** historical decline from paleo benchmarks; recognizes role of forest management and fire suppression.
- **Downplays recent severity:** While burn acreage has not increased linearly, NIFC and NASA have documented longer seasons and higher fire intensity, especially in western U.S.

Other Extremes (Tornadoes, Floods, Droughts)

- **Correctly reflects IPCC’s low confidence** in observed trends.
- **Droughts:** Right that CONUS-wide dryness hasn’t worsened—but omits growing consensus on **agricultural drought stress** under warming conditions, soil moisture decline, and evapotranspiration effects.

Potential Bias: Moderate-to-Strong Skeptical Framing

Feature	Bias Indicators
 Language Tone	Repeated use of skeptical phrases (“naïve to assume,” “misleading metric”)
 Citation Pattern	Strong reliance on contrarian researchers; mainstream climate scientists undercited
 Selective Trend Analysis	Uses longer timespans or alternate baselines to undercut positive trend signals

Feature

Bias Indicators

Emphasis Strategy

Highlights variability and uncertainty to argue against attribution

Summary

This chapter presents **technically sound data handling**, especially in its treatment of statistical uncertainties and autocorrelated extremes. However, it leans toward **minimizing human influence** on extreme weather by emphasizing natural variability and critiquing conventional metrics. That's not inherently invalid—but the presentation sometimes slides from **scientific critique into rhetorical positioning**, especially by omitting competing interpretations and framing past extremes as a nullifying baseline.

Steve, this is a heavy-hitting section—covering **sea level rise and attribution science**, and it's packed with technical nuance. Here's my detailed critique, broken down by theme for readability and rigor:

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To: 'Judith Curry'
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Subject: RE: MS Copilot detailed critique
Attachments: ~WRD2393.jpg

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- ? **Accurate distinction** between detection and attribution, with good explanations of short data record limitations and long-term persistence (LTP).
- ? **Valid caution** on short-term statistical inference: The use of paleoclimate data and historic Nile flow is a strong point for contextualizing variability.

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- ? **Selective emphasis**: Downplays emerging consensus on increased major hurricane *intensity* driven by SSTs and thermodynamic conditions, which IPCC acknowledges with *medium confidence*. Mentions Maue's dataset prominently, but **omits broader literature** on storm surge or rainfall increases.

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- ? **Data analysis appears methodologically sound**, especially long-term USHCN station metrics.
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- ? **Valid critique** of short-term trend identification, with good treatment of clustering and autocorrelation in extreme rainfall.

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- ? **Well-documented** historical decline from paleo benchmarks; recognizes role of forest management and fire suppression.
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- ? **Correctly reflects IPCC's low confidence** in observed trends.
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Feature	Bias Indicators
· Language Tone	Repeated use of skeptical phrases (“naïve to assume,” “misleading metric”)
· Citation Pattern	Strong reliance on contrarian researchers; mainstream climate scientists undercited
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This chapter presents **technically sound data handling**, especially in its treatment of statistical uncertainties and autocorrelated extremes. However, it leans toward **minimizing human influence** on extreme weather by emphasizing natural variability and critiquing conventional metrics. That’s not inherently invalid—but the presentation sometimes slides from **scientific critique into rhetorical positioning**, especially by omitting competing interpretations and framing past extremes as a nullifying baseline.

Steve, this is a heavy-hitting section—covering **sea level rise and attribution science**, and it's packed with technical nuance. Here’s my detailed critique, broken down by theme for readability and rigor:

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• **Summary Table**

Theme	Strengths	Concerns
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Cloud/Albedo Effects	Novel explanation for recent warming surge	Speculative feedback interpretation; short data window

Steve, this section demonstrates real analytical heft, but the **bias emerges through omission and slanting rather than data distortion**. It’s more of a critique manifesto than a balanced review—but that makes it rich ground for public discourse.

Thanks, Steve—this final section wraps up the report with **policy implications, energy strategy, and scientific process critique**, and it’s loaded with ideological framing. Let’s break it down with the same clarity and rigor:

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- ? **Technically correct** that U.S. emissions reductions alone won't halt global warming—climate is a global system.
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- **Peer Review and Funding**

- ? **Valid critique of gatekeeping:** Concerns over funding bias and editorial control are echoed in discussions about reproducibility and publication incentives.
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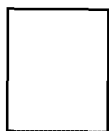
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This concluding section shifts from *scientific critique* to **ideological rhetoric**, using energy economics and institutional skepticism to challenge mainstream climate policy. While there are **valid points on technology limitations and scientific incentives**, these are **wrapped in a narrative of distrust**—painting climate action as misguided zealotry rather than pragmatic response.

Steve Koonin



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CFAN - Climate Forecast Applications Network
Reno, NV USA
curry.judith@cfanclimate.com | +1.404.803.2012
<http://www.cfanclimate.net>

From: Judith Curry <curry.judith@gmail.com>
Sent: Thursday, July 10, 2025 1:25 PM
To: Steven Koonin
Cc: John Christy; Ross McKittrick; Roy Spencer; Josh Loucks; Travis Fisher
Subject: Re: MS Copilot detailed critique

This is amazing, far better than what we would get from "real" scientists

I'm going through Ross' latest version to look for "Skeptic talk" and red flag words

On Thu, Jul 10, 2025 at 10:10 AM Steven Koonin <steven.koonin@gmail.com> wrote:

Had to split the CWG25 report into 5 sections. Here are the concatenated responses, separated by red lines:

Here's a detailed critique focused on **scientific accuracy** and **potential bias**, based on what I've seen so far:

Scientific Accuracy: Mixed Signals

Global Greening & CO₂ Fertilization

- **Accurate observations:** The report correctly notes satellite-confirmed global greening, with increased Leaf Area Index (LAI) and enhanced plant growth due to rising CO₂.
- **Selective emphasis:** It heavily leans on CO₂ as beneficial, citing fertilization benefits while **minimizing caveats**—such as nutrient limitations, heat stress, and species-specific responses that constrain agricultural benefits.
- **Outdated or narrow sourcing:** Some of the cited studies, while valid, don't reflect **broader scientific consensus**. For example, while FACE experiments show CO₂ boosts productivity, they also warn of **diminished gains under warming, drought, and soil depletion**.

Ocean "Acidification"

- **Terminology critique has merit:** The report accurately points out that "acidification" is a misnomer—the oceans remain alkaline.
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- **Publication bias claim:** The document references well-known concerns about bias toward dramatic findings. That's valid—but it misses the nuance: **many reproducible studies do show physiological stress** in marine organisms, even under moderate pH change.

Potential Bias: Framing & Rhetorical Strategy

✓ Strengths

- **Independent tone:** The authors claim editorial freedom, which lends credibility.
- **Acknowledgement of complexity:** The report does mention uncertainties, including model over-sensitivity and limitations of attribution science.

► Sources of Bias

- **Language framing:** Words like “*exaggerated*,” “*one-sided*,” “*alarmist*,” and “*science fiction*” appear frequently. This rhetorical tone may compromise the objectivity typically expected in a scientific review.
- **Selective citation:** Heavy use of contrarian sources (e.g., Christy, Spencer, McKittrick) without balancing perspectives from mainstream climate literature (e.g., IPCC Working Groups, NOAA, NASA) suggests bias.
- **Motivated skepticism:** The narrative implies that benefits of CO₂ (e.g., plant growth, energy use) outweigh potential harm, which reflects a **value-laden interpretation** rather than a neutral scientific synthesis.

✦ Summary

This section offers **legitimate critiques** of some dominant narratives, but the scientific review is **imbalanced**:

- Evidence is often cherry-picked to support a CO₂-positive view.
- Legitimate concerns about uncertainty and model bias are mixed with selective omission of broader literature.
- The rhetorical tone leans toward climate contrarianism rather than impartial synthesis.

🏠 Scientific Accuracy: Solid Points + Selective Framing

🔧 Equilibrium Climate Sensitivity (ECS)

- **Accurate baseline:** The document correctly notes that direct CO₂ forcing yields ~1°C warming, and additional warming comes from feedbacks like water vapor, albedo, and clouds.
- **Model tuning concerns:** Valid criticisms are raised about GCM tuning, especially regarding cloud feedbacks. Quoting modelers who explicitly tuned ECS to match observed warming is compelling.
- **Cloud feedback uncertainty:** The discussion of cloud parameterization difficulties is largely accurate and aligned with published literature (e.g. Zelinka et al., 2020).

■ Data-Driven vs. Model-Derived ECS

- **Balanced coverage of paleoclimate:** It notes the wide uncertainties in paleoclimate ECS estimates—fair and scientifically supported.
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- **Fair representation:** Comparison between Lewis and IPCC values shows tighter consensus on TCR than ECS, with both landing between 1.2–2.4°C. This part is more neutrally presented.

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📖 Rhetorical Techniques

- **Loaded phrasing:** Terms like “not fit for purpose,” “tuning for target ECS,” and “model failure” are used liberally. While these phrases reflect genuine debate, their repetition gives a tone of **advocacy** more than impartial analysis.
- **Source imbalance:** Heavy emphasis on papers by Christy, McKittrick, Lewis, and Spencer—valid critiques, but **underrepresents mainstream modeling community responses**, such as those in IPCC technical annexes.

■ Model vs Observation Mismatch

- **Highlighted issues:** Mismatches in tropospheric warming, stratospheric cooling, and snow cover are well-documented and deserve scrutiny.
- **Interpretive bias:** The report implies these mismatches invalidate model projections or anthropogenic attribution. But many of these discrepancies are acknowledged in IPCC reports with medium confidence levels, and **don't nullify the broader warming trend**.

🔍 Vertical Temperature Profiles

- **Strong visual critique:** Figures show warming biases in CMIP6 models relative to radiosonde and satellite data—visually compelling.
- **Interpretive overreach:** The conclusion that observed profiles are “consistent with no GHG forcing” is **unsupported** by broader fingerprinting literature (e.g., Santer et al., 2008).

✚ Summary of the Section

Aspect	Strengths	Limitations/Concerns
ECS Discussion	Strong on cloud feedback and model tuning critiques	Overstates certainty of low ECS; cherry-picks supportive sources
Data vs Model Comparison	Fair TCR coverage; Paleoclimate uncertainty noted	Pattern effect critique presented as settled science
Model Mismatch Evidence	Detailed and compelling visuals; well-cited contrarian work	Limited engagement with IPCC counterpoints or rebuttals
Tone and Rhetoric	Engaging and readable for a skeptical audience	Leans toward climate contrarian narrative over balanced synthesis

Excellent, Steve—this section takes us through a nuanced tour of **extreme weather trends**, and it's rich with statistical depth. Here's a critique focused squarely on **scientific accuracy** and **potential bias**, organized by topic for clarity:

Scientific Accuracy: Statistically Rigorous, Selectively Interpreted

General Framing of Extremes

- **Accurate distinction** between detection and attribution, with good explanations of short data record limitations and long-term persistence (LTP).
- **Valid caution** on short-term statistical inference: The use of paleoclimate data and historic Nile flow is a strong point for contextualizing variability.

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Reno, NV USA
curry.judith@cfanclimate.com | +1.404.803.2012
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From: Steven Koonin [steven.koonin@gmail.com]
Sent: 7/10/2025 5:10:00 PM
To: 'John Christy' [climateman60@gmail.com]; 'Ross McKittrick' [ross.mckittrick@gmail.com]; 'Roy Spencer' [roywspencer@hotmail.com]; 'Judith Curry' [curry.judith@gmail.com]; 'Josh Loucks' [loucksj14@gmail.com]; 'Travis Fisher' [travis.scott.fisher@gmail.com]
Subject: MS Copilot detailed critique

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茶 Rhetorical Techniques

? **Loaded phrasing:** Terms like “not fit for purpose,” “tuning for target ECS,” and “model failure” are used liberally. While these phrases reflect genuine debate, their repetition gives a tone of **advocacy** more than impartial analysis.

? **Source imbalance:** Heavy emphasis on papers by Christy, McKittrick, Lewis, and Spencer—valid critiques, but **underrepresents mainstream modeling community responses**, such as those in IPCC technical annexes.

□ Model vs Observation Mismatch

? **Highlighted issues:** Mismatches in tropospheric warming, stratospheric cooling, and snow cover are well-documented and deserve scrutiny.

? **Interpretive bias:** The report implies these mismatches invalidate model projections or anthropogenic attribution. But many of these discrepancies are acknowledged in IPCC reports with medium confidence levels, and **don’t nullify the broader warming trend**.

□ Vertical Temperature Profiles

? **Strong visual critique:** Figures show warming biases in CMIP6 models relative to radiosonde and satellite data—visually compelling.

? **Interpretive overreach:** The conclusion that observed profiles are “consistent with no GHG forcing” is **unsupported** by broader fingerprinting literature (e.g., Santer et al., 2008).

□ Summary of the Section

Aspect	Strengths	Limitations/Concerns
ECS Discussion	Strong on cloud feedback and model tuning critiques	Overstates certainty of low ECS; cherry-picks supportive sources
Data vs Model Comparison	Fair TCR coverage; Paleoclimate uncertainty noted	Pattern effect critique presented as settled science
Model Mismatch Evidence	Detailed and compelling visuals; well-cited contrarian work	Limited engagement with IPCC counterpoints or rebuttals
Tone and Rhetoric	Engaging and readable for a skeptical audience	Leans toward climate contrarian narrative over balanced synthesis

Excellent, Steve—this section takes us through a nuanced tour of **extreme weather trends**, and it’s rich with statistical depth. Here’s a critique focused squarely on **scientific accuracy** and **potential bias**, organized by topic for clarity:

□ Scientific Accuracy: Statistically Rigorous, Selectively Interpreted

□ General Framing of Extremes

- ? **Accurate distinction** between detection and attribution, with good explanations of short data record limitations and long-term persistence (LTP).
- ? **Valid caution** on short-term statistical inference: The use of paleoclimate data and historic Nile flow is a strong point for contextualizing variability.

□ Hurricanes

- ? **Correct on satellite-era confidence** and AMO-driven variability. Charts support lack of long-term trends in total hurricanes.
- ? **Selective emphasis:** Downplays emerging consensus on increased major hurricane *intensity* driven by SSTs and thermodynamic conditions, which IPCC acknowledges with *medium confidence*. Mentions Maue’s dataset prominently, but **omits broader literature** on storm surge or rainfall increases.

□ Temperature Extremes

- ? **Data analysis appears methodologically sound**, especially long-term USHCN station metrics.
- ? **Correct that 1930s heatwaves were exceptional**, and that nighttime warming (Tmin) has likely UHI influence. This reflects mainstream debate.
- ? **Skews interpretation:** The narrative implies a “milder” climate based on reduced extremes. That’s contentious. IPCC and NCA emphasize increased heatwave *risk, not just frequency*, especially in vulnerable regions.

□ Precipitation Extremes

- ? **Valid critique** of short-term trend identification, with good treatment of clustering and autocorrelation in extreme rainfall.
- ? **Cherry-picked references** (e.g., McKittrick & Christy studies) are robust, but **contrary literature** suggesting regional increases (e.g., Kunkel et al.) is omitted.
- ? **Conclusion that trends vanish when starting earlier** is methodologically reasonable but glosses over physical mechanisms linking warming to increased atmospheric moisture and rain intensity.

□ Wildfires

- ? **Well-documented** historical decline from paleo benchmarks; recognizes role of forest management and fire suppression.
- ? **Downplays recent severity:** While burn acreage has not increased linearly, NIFC and NASA have documented longer seasons and higher fire intensity, especially in western U.S.

□ Other Extremes (Tornadoes, Floods, Droughts)

- ? **Correctly reflects IPCC’s low confidence** in observed trends.
- ? **Droughts:** Right that CONUS-wide dryness hasn’t worsened—but omits growing consensus on **agricultural drought stress** under warming conditions, soil moisture decline, and evapotranspiration effects.

易 Potential Bias: Moderate-to-Strong Skeptical Framing

Feature	Bias Indicators
□ Language Tone	Repeated use of skeptical phrases (“naïve to assume,” “misleading metric”)
□ Citation Pattern	Strong reliance on contrarian researchers; mainstream climate scientists undercited
□ Selective Trend Analysis	Uses longer timespans or alternate baselines to undercut positive trend signals
□ Emphasis Strategy	Highlights variability and uncertainty to argue against attribution

茶 Summary

This chapter presents **technically sound data handling**, especially in its treatment of statistical uncertainties and autocorrelated extremes. However, it leans toward **minimizing human influence** on extreme weather by emphasizing natural variability and critiquing conventional metrics. That’s not inherently invalid—but the presentation sometimes slides from **scientific critique into rhetorical positioning**, especially by omitting competing interpretations and framing past extremes as a nullifying baseline.

Steve, this is a heavy-hitting section—covering **sea level rise and attribution science**, and it's packed with technical nuance. Here’s my detailed critique, broken down by theme for readability and rigor:

□ Sea Level Rise: Strong Data, Biased Framing

□ Observational Accuracy

? **Global trend well-stated:** 8 inches of global rise since 1900 aligns with established satellite and tide gauge records.

? **Regional differentiation is robust:** The report correctly distinguishes between *absolute* sea level rise and *relative* rise due to subsidence—essential for sites like Galveston, Grand Isle, and NYC.

? **Use of vertical land motion (VLM) data** is technically strong and mirrors best practices in geodesy (Wöppelmann & Marcos, 2016).

□ Downplaying Acceleration

? Asserts that “no obvious acceleration” exists post-1993—this conflicts with satellite altimetry showing increased rates since then (see Nerem et al., 2018).

? **Misinterpretation of NOAA projections:** Suggests future rise is implausible because recent data hasn't matched model forecasts. But these projections account for *nonlinear glacier and ice sheet loss*, which may manifest later this century.

? **Heavy critique of IPCC scenarios:** Focuses on SSP5-8.5 as unrealistic—which is fair—but skips middle-range pathways like SSP2-4.5 that still yield substantial rise.

□ Attribution of Warming: Technically Sophisticated, Methodologically Skeptical

☞ Attribution Methods

? The summary of **fingerprinting, time series, and process-based approaches** is solid and consistent with IPCC technical chapters.

? Highlights statistical limits and expert judgment—important caveats that the IPCC often emphasizes but mainstream summaries gloss over.

□ Critique of Optimal Fingerprinting

? Leans heavily on McKittrick's critique, citing bias in regression methods (Total Least Squares). This is part of a **legitimate academic debate**, but the report implies it **invalidates** attribution studies entirely, which goes beyond what McKittrick himself claims.

? **Missing balance:** Doesn't explore alternative attribution methods that reinforce anthropogenic fingerprints (e.g., Hausfather & Peters, 2020; Santer et al., 2019).

⚙️ Role of Natural Variability: Thorough, but Overstated

□ Solar Forcing

? Presents nuanced review of Total Solar Irradiance (TSI), noting conflicting composites and possible indirect effects—strong science communication here.

? **Selective emphasis on uncertainty:** Quotes high-end studies suggesting up to 70% of warming from solar variability (Scafetta et al.), but downplays the robust attribution literature showing limited solar impact post-1970s.

□ Ocean Oscillations

? Captures legitimate concerns about phasing of multidecadal modes (PDO, AMO) in CMIP6.

? **Overstates masking effect:** Suggests ensemble averaging erases natural variability contributions, ignoring that these are explicitly addressed in uncertainty ranges.

? **Implied causality** between the 1976 PDO shift and modern warming trends is speculative and not broadly supported by recent literature (e.g., Kaufman et al., 2020).

☁ Declining Albedo & Cloud Cover: Emerging, Not Settled Science

? Notes a sharp **1.7 W/m² radiative impact from recent albedo decline**, which rivals CO₂ forcing. That's a bold claim—but the satellite record and cloud variability studies do indicate substantial recent change.

? **Plausible hypotheses:** ENSO cycles, changes in shipping aerosols, and the Hunga-Tonga eruption are reasonably proposed drivers.

? **Pushes speculative feedbacks:** Asserts a new positive cloud feedback starting in 2015, but this lacks mechanistic grounding and long-term data.

□ Summary Table

Theme	Strengths	Concerns
Sea Level Rise Data	Technically rigorous; strong separation of RSLR and ASLR	Downplays acceleration; selectively interprets NOAA forecasts
Attribution Methods	Clear method descriptions; valid critiques of fingerprinting	Overstates model bias; omits balanced counterviews
Natural Variability	Deep review of solar/ocean signals	Overemphasizes uncertainty; hints at deterministic phasing
Cloud/Albedo Effects	Novel explanation for recent warming surge	Speculative feedback interpretation; short data window

Steve, this section demonstrates real analytical heft, but the **bias emerges through omission and slanting rather than data distortion**. It's more of a critique manifesto than a balanced review—but that makes it rich ground for public discourse.

Thanks, Steve—this final section wraps up the report with **policy implications, energy strategy, and scientific process critique**, and it's loaded with ideological framing. Let's break it down with the same clarity and rigor:

🔍 Scientific Accuracy: Mixed Quality with Heavy Editorialization

☐ Energy Strategy & Climate Action

- ? **Correct economic observation:** Notes the disproportionate cost burden of decarbonization on developing nations, echoing concerns raised in international energy analyses.
- ? **Valid technical constraints:** Points out intermittency issues with wind/solar and rare earth supply for batteries—these are real engineering challenges and reasonably described.
- ? **Oversimplifies alternatives:** Frames nuclear, natural gas, and coal as straightforward solutions without adequately addressing lifecycle emissions, waste disposal, or geopolitical constraints.

☐ CO₂ Reduction Effectiveness

- ? **Technically correct** that U.S. emissions reductions alone won't halt global warming—climate is a global system.
- ? **Spins limitation into futility:** Uses this to argue against domestic mitigation, ignoring multiplier effects, tech spillover, and diplomatic leverage of leadership.

🌊 Scientific Process Critique: Flawed but Thought-Provoking

☐ Peer Review and Funding

- ? **Valid critique of gatekeeping:** Concerns over funding bias and editorial control are echoed in discussions about reproducibility and publication incentives.
- ? **Overstates malfeasance:** Asserts that dissenting scientists are “suppressed” or “blacklisted,” which lacks supporting evidence and veers into conspiracy territory.

☐ Consensus Framing

- ? **Challenges the “97%” claim:** Points out methodological limitations in consensus surveys—some fair critique here.
- ? **Misrepresents dissent:** Suggests that the mere existence of contrarian papers invalidates consensus, ignoring scientific weight of evidence and replication.

🔍 Potential Bias: Strong Ideological Framing

Feature	Indicators of Bias
☐ Tone	Emotive language (“groupthink,” “virtue signaling,” “green dogma”)
☐ Source Pattern	Heavily reliant on politically-aligned think tanks and contrarian experts
☐ Argument Strategy	Appeals to economic hardship and energy realism to dismiss science-led mitigation
☐ Policy Framing	Portrays climate action as a moral panic and economic self-harm

□ Summary

This concluding section shifts from scientific critique to **ideological rhetoric**, using energy economics and institutional skepticism to challenge mainstream climate policy. While there are **valid points on technology limitations and scientific incentives**, these are **wrapped in a narrative of distrust**—painting climate action as misguided zealotry rather than pragmatic response.

Steve Koonin

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Comment or Suggested Edit

In general, criticism and re-analysis of past research is always welcome. This report summarizes some substantial concerns from a small group of researchers. The report should be reframed to reflect this and I provide some suggestions in a later comment. I suspect that simply publishing this report will not offset the hundreds of reports and publications on CO2 and Climate that have come before it. But, new analyses and communication within and outside the research community could make a positive difference, should the findings in this report be substantiated. The DOE Office of Science BER could be provided an opportunity to address the research uncertainties in this document in a thorough and robust manner.

As someone who used to read the DOE reports on CO2 as a graduate student in the 1990s and then conducted numerous analyses of carbon on many topic areas which were later confirmed by numerous other analyses, it seems somewhat cavalier for DOE to issue one brief conclusive report on the "impacts of carbon dioxide emissions". I suggest the following option: Change the title to "Topics of Uncertainty on the Impacts of Carbon Dioxide Emissions on the U.S. Climate" or "**An Assessment of CO2 Impacts on Climate to Guide Future Research**", and then use this report to drive research/analyses for each report chapter which would conclude in separate topical reports that could be finished within a year or two. In doing so, the DOE would positively contribute to addressing some of these standing issues and hopefully enable the nation to move forward in a more productive manner.

I appreciate the perspective. It could be useful to add or edit the Secretary's Forward to indicate that "**the report has been purposefully commissioned to researchers with alternative perspectives in an effort to address these perspectives and provide some closure for the American public, the US Economy, and US energy policy.**" I suggest this, because it will be very obvious that a handful of skeptics were chosen out of literally hundreds of extremely active and well-respected scientist. Addressing that upfront will immediately reduce criticism, and hopefully generate a positive environment to address these issues. Everyone would like to see convergence of findings on these issues.

Any increase in greening from additional CO2 will likely be more than offset by longer growing seasons with higher temperatures (i.e., more days over 100). This causes serious risk to the US midwestern "bread basket", which is why this has been considered a national security concern. The data supporting this trend has been published a few times now in Science by a fellow out of Stanford, among others. Sources: Lobell and Field. 2007, doi: 10.1088/1748-9326/2/1/014002; also Sloat et al. 2020, doi:10.1038/s41467-020-15076-4 has a thorough introduction with many citations.

My understanding is that the upper bound of emissions (i.e., very high) is business as usual, with no mitigation, and a high-end of growth. It's a worst, yet plausible, case scenario. Similarly, the lowest emissions (i.e., very low) scenario includes technologies that don't yet exist including significant CO2 removal. Both are there to understand plausible extremes. The more likely scenarios are the low to high scenarios. I'm sure researchers are open to revisiting how things are bounded and presented if there are reasonable objections. This may be true. But data driven analyses may not capture anticipated feedbacks.

I am a big fan of data and meta-analysis. However, I'll note that I do not think forest management practices are overlooked. In fact, it is one of the main driving story lines (i.e., too much fuelwood exists, so we need to harvest more forest). There remains strong debate on the efficacy of fuelwood removal over large areas as an effective means of wildfire reduction. The key to this analysis is to look at whether the extent (not the numbers) of fires has grown and whether the burned areas are returning to forests or returning to brush or grassland. If it's the latter, then that is more likely due to regional changes in climate (temp and precipitation).

I think we can point to sea-level rise in south florida, crop damage, and disease vectors fairly easily. I'm not aware of what costs are associated with these 3 items, but I suspect it's quite large.

Yes, this is an important paragraph. Most scientists are not activists. Just because there is a science finding, scientists don't expect that to turn into policy. The public and the democratic system can determine the policy using an evidence-based risk/benefit analysis, just as noted here. Opening up this conversation (which should have been done decades ago) would be welcome and would better engage the public on this issue. DOE could in fact take a leading role here and help address a major national issue.

This is all generally correct. I would like to think this is common knowledge.

Why use studies based on satellite sensors? I'm quite sure there are studies (again, out of Stanford) that use historic yield data (county-scale USDA data and global FAO data) with associated temperature and precipitation data. Those analyses do not agree with your findings here, I think. But, we can certainly pose these questions to our scientists that study and develop land models and develop a report based on all available data. I'll also note that for sometime data synthesis wasn't considered fundamental science and was therefore largely ignored. Enabling the researchers to conduct robust data analyses on this and other topics would be largely welcomed. All data is interesting and useful for perspective and understanding. But isn't the main question whether we are driving up CO2 and temp at a rapid pace in the post-industrial era? This graph does not help answer that question.

Stating that increased aridity in drylands will not lead to decreased productivity seems a bit questionable. We can point to precipitation gradients from high to low precipitation that supports forests to grasslands to shrublands, respectively. Less water in general will mean less productivity; this can be seen in different forest compositions as well. The authors cite Zhang et al. (2014), but Zhang's main point is that the direct CO2 effect may be causing greening in drylands that offsets the decreased precipitation. This may be more specific to dryland vegetation, and Zhang et al. specifically state that this finding is relevant to north-east Brazil, Namibia, western Sahel, Horn of Africa, and central Asia.

I do not disagree with this observation of a decline effect, and I have seen it in some of the early biomass energy analyses that appeared in prominent journals and were then corrected over a few years. While it is unfortunate that some try to grab headlines with unsupported assumptions, it does seem that other researchers tend to provide counter arguments and analyses fairly quickly, indicating that the system does in fact work fairly well.

Yes, CO2 uptake by land processes have uncertainty associated with them. It's worth noting that DOE researchers (many of whom are retired now) were world-leading and making progress in this area, but nearly all work on CO2 uptake and emissions stopped 10-15 years ago due to political pressure and political concerns. The Carbon Dioxide Information and Analysis Center at ORNL, now cancelled, was a main contributor to the Global Carbon Project. Now the US is woefully behind and ceding expertise on this to the Europeans (as cited in this report). We are also ceding expertise on carbon monitoring via satellites to other countries. There's nothing necessarily wrong with this if this is where the US wants to go, but it's important to recognize that we have lost significant capacity due to policy changes over many years.

Some of the early work on this topic was done by researchers at Stanford. But there are plenty of other papers. Here's one that came up in a quick search: <https://www.pnas.org/doi/10.1073/pnas.0906865106> Contradicting a number of large meta-analyses on the topic of decreased yields with increased temperature is ok. That's what science is all about. But it's going to have to be done in a more robust way than a couple paragraphs here with one or two citations. This is very important. I have not dug into the data on extreme storm data (both numbers and intensity). Getting researchers together that disagree on a topic, analyze the data, and publish findings together can be very productive. DOE could sponsor a workshop and bring together a broad range of experts and find answers to extreme weather trends.

I conducted some analyses on wildfire years ago. I saw the bias in the university textbooks and in the wildfire working groups, who essentially went by textbook teachings. It was rare that people went back to the original data. The last time I checked the actual data (a good 10 years ago), I found that...you're correct...the number of fires had not changed much. What does seem to be changing is that the extent of fires has grown, and this is mostly attributable to hotter and drier conditions. I do not believe there is more fuel load now than there was before the US was settled. Arguing that harvesting will decrease fire is nonsensical; you have no idea where the lightning is going to strike and subsidizing the thinning of all forest in the western fire zone would be cost prohibitive. I think we need to stop using wildfire management as a justification for harvesting. If we want to harvest more, than do it, and stop using fuel load arguments (which is more of a concept than proven reality) as a reason to do it. The biggest issue here is encroachment of housing communities into the Wild-Urban Interface (WUI) and how we want to handle that with policies. Fire is really only bad if it's burning someone's house down. Otherwise, it's a natural progression in forest dynamics. Sources: Campbell et al. 2012. doi:10.1890/110057.; Schoennagel and Nelson. 2011. doi:10.1890/090199.

The NCA5 is cited here and elsewhere. However, the USGCRP website that hosts the NCA reports has been removed. Hence, there is no way to read and review the referenced findings. This DOE report is therefore arguing against something that no longer exists, and that may appear questionable.

Given the satellite observed ice sheet dynamics, I'm not sure that ice sheet retreat is that hypothetical. This is the first time I have seen all sea-level rise estimates discredited by an offset from land subsidence. This is certainly a global dynamic that we would want to capture and understand in Earth system models, and DOE can look into this further with analyses and experiments if necessary.

This and other chapters cite the IPCC AR6. The IPCC provides a global process to address the issues and uncertainties in this report. Perhaps this report can set a path for pivoting research and re-engaging in a useful manner.

The last sentence in this summary is not necessarily accurate. The authors cite Ainsworth and Long (2020) with respect to increased CO2 effects on crops. But, Ainsworth and Long (2020) indicate that increased temp and decreased precipitation will have negative impacts on crops, while increased CO2 may offset some of those negative effects. It is the impact of CO2 on climate and the subsequent impact on crops that is the concern; not the direct effect of CO2 on crops.

From: Judith Curry <curry.judith@gmail.com>
Sent: Sunday, July 20, 2025 8:18 PM
To: Fisher, Travis
Cc: climateman60@gmail.com; roywspencer@hotmail.com; ross.mckitrick@gmail.com; steven.koonin@gmail.com; Cohen, Seth; Loucks, Joshua
Subject: Re: Fw: Update: Technical reviewers

Well this is interesting. I like the suggestion that we list major uncertainties for future research but that seems to be more of a task for the NCA6 recommendations

On Sun, Jul 20, 2025 at 4:08 PM Fisher, Travis <travis.fisher@hq.doe.gov> wrote:
FYI.

I haven't reviewed these comments yet, just passing them along before I get on a flight back to DC.

From: [REDACTED]
Sent: Sunday, July 20, 2025 4:44 PM
To: Fisher, Travis <travis.fisher@hq.doe.gov>; [REDACTED]
Cc: [REDACTED]
Subject: RE: Update: Technical reviewers

Travis,

My review is attached. I don't have the technical depth at this point in my career that the Lab scientists do. But my top-level comment is that this report would be really helpful to DOE (and I assume the secretary) if it was more explicit about the biggest scientific uncertainties, where further research is most needed. If the authors could add a brief section listing these and prioritizing these uncertainties, it could be extremely helpful. I suspect this would also make the report more palatable to the science community.

The secretary's remarks could highlight this as a key purpose of the report as well, and I believe this would increase the interest of the audience.

[REDACTED] is also doing a review, so he can share his comments separately.

[REDACTED]

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Comment or Suggested Edit

helpful if these undertainties were made more explicit, listed in a concluding section, and prioritized in some way - what are the top 10 priority research areas? If the opening remarks by Secretary Wright and the title pointed to uncertainties and the need for more research, I believe this report will be better received. As I read the report and left review comments below, **I bolded items where I gather the**

This would be more correct: "Some scenarios of future CO2 emissions overestimate observed levels"

This would be more correct: Some detailed climate models run "hot" in their simulation of the climate of the past few decades, while many have underestimated the amount of surface warming. **More research is needed to**

Need reference for: "Claims of increased frequency or intensity of hurricanes, tornadoes, floods, and droughts are not supported by historical data." **More research is needed to identify how frequency and intensity of**

It is misleading to separate the photo-chemical effects of CO2 from the temperature effects. Extreme heat is hard on plants, causing them to lose water, close stomata, etc. It depends on the plant and the degree of heat. **More**

Again it is misleading to separate the CO2 and the temperature effects on the oceans. The warming surface waters is having significant impact on ocean fish and habitats due to the overall increase in global temperatures

More accurate to say "because their effect remain largely unknown". Good examples include natural aerosols (sea salt, dust, biogenic aerosols). Are there others to mention? **More research is needed to understand**

What scenarios are the models using in this figure?

Vegetation is only one way that CO2 is accommodated by land processes, the other is through soils and microbial processes Microbial dynamics is complex and challenging to understand but may also be a way to boost CO2

absorption by soils (which also enriches the soil nutrients!). **More research is needed to better understand how**

More research is needed to improve the understanding and representation of land systems, carbon and

Carbon uptake by oceans and ocean ecosystems is less well studies and modeled. The lack of spread of carbon in ocean models may result from insufficient information, ocean biogeochemistry, ecosystems and model

development. **More research is needed to study and model carbon, nutrient and ecosystem processes and**

More research is needed to map warming trends in urban, non-urban and other environments and to ensure accurate representation of regional and global trends in temperature.

"This practice" - need to clarify whether this refers to "emergent property" or discarding. I believe the authors

"assumed positive cloud feedback" - this is an emergent property too, based on simulation/observation. Should be rephrased to not use the word "assumed". **Further research is needed to better understand and model how**

Further research is needed to narrow the uncertainty on climate sensitivity, both using models and

The text and figure refer to 33 models, which would include the best and worst. How much does the

How many models are included in each case?

How are the lower and mid-troposphere defined?

"excess amplification" - amplification of what? And Figure 5.6 shows tropics, is this bias only tropical?

Further research is needed to improve how models represent clouds and dynamics; additional observations

Further research is needed to improve how models represent planetary albedo to align with observations.

The greater concern with hurricanes is the amount of moisture the carry and drop after landfall, i.e. flooding.

While this is an active area of research, it is worth noting that this may be the bigger issue for hurricane change

The concern for many are the extreme hot temperatures without night-time cooling that provides an opportunity for recovery. This section doesn't address this. In this regards, the focus on the difference between extreme hot

and extreme cold is misleading when generalizing about decrease in extremes (figure 6.3.4) - the decrease is

Combining heat and humidity as a measure of extreme heat is not unusual since it is this combination that is most impactful to human health - the body cannot cool if the humidity and heat are both high. Since a warmer atmosphere holds more moisture, and CO2 causes heat (and therefore moisture) to increase, this combination is a relevant assessment of the effects of CO2 on extreme conditions that make it difficult for people. Also

Patterns and variability of precipitation are poorly understood and models are particularly challenged to represent and predict precipitation, further research in this area is needed

The authors rightly describe the extreme uncertainty regarding sea level rise. It would be helpful to add some information about the complex, highly nonlinear and uncertain processes involved with ice-sheet dynamics and ice-sheet - ocean interactions that are especially key for Antarctica. **More research is needed to study and model**

Further research is needed on climate variability, effects of ocean circulation, solar variability, model

Anthropogenic aerosol effects may also influence the inflections in temperature in ways that are challenging to Reductions in aerosol indirect (cloud brightening) effects may also explain the reduced planetary albedo, not just from ships but from reduced fossil fuel aerosols coming from the continents, China and east asia especially. This paper describes the reduction in aerosols <https://www.nature.com/articles/s41612-023-00488-y> **This is another** What are the numbers in the 3rd column? Please include in the caption.

I don't see an inconsistency between what Ch 11 and Ch 8 say. The first is about precipitation, droughts, tropical cyclones, heat - overall. The 2nd (ch 8) is about specific types of events in specific regions. Suggest to soften the

The science of attribution of extreme events is challenging and computationally expensive; this is an area where further research is needed with potential to use AI to improve statistics

This section seems to gloss over many key points. Certainly there are limits where extreme heat and drought (water is key) could be detrimental to crops. It also depends on which crops. There is extensive literature on how certain crop viability is shifting. So a region with particular crop experience and cultivation may no longer be able to sustain that agriculture. There is cost to shifting crops across regions and farmers that needs to be accounted Severe weather continues to disproportionately impact lower income communities as well as business that requires outdoor exposure. A thorough analysis would need to include these points and I recommend adding this Related to my previous comment, deaths due to extreme heat conditions appear to be increasing, particularly for certain populations and for those with underlying health conditions (which can be hard to detangle when An additional concern is if the grid fails under either extreme heat demands or cold/severe-storm events, the impact on communities will not be uniform and depends on grid infrastructure which can be better in more The impacts of sea level rise and coastal inundation on coastal communities and in low-lying countries should be addressed. This will have impacts particularly on certain countries/regions but also on world economics

Research is needed to better understand the likelihood and impacts of various tipping points, including changes to ocean circulation patterns, ice sheet acceleration, sea-ice loss, die-off of tropical forests, thawing of

Do the authors think it worthwhile for private or public research, such as at DOE, to seek breakthrough technology that might effectively remove massive amounts of CO2 from the atmosphere?

From: Fisher, Travis <travis.fisher@hq.doe.gov>
Sent: Sunday, July 20, 2025 10:26 AM
To: Judith Curry; John Christy
Cc: roywspencer@hotmail.com; ross.mckitrick@gmail.com; Steve Koonin; Loucks, Joshua; Cohen, Seth
Subject: RE: [EXTERNAL] Draft DOE report for review
Attachments: Review 1.docx

The attached document includes all comments from Reviewer 1 (with references now added below each comment), Judy's proposed responses in red, and John's proposed responses in blue. Let's stick with the Word format from here on out—I agree the Excel version is a mess.

I haven't received any other reviews yet. I will try to get each reviewers' comments in this same format as they come in. Note that they have until the end of the day on Monday (midnight ET Monday deadline) to offer comments.

Is everyone ok with me using MS Teams to set up the Tuesday conference call? And what's the best time to get started?

From: Judith Curry <curry.judith@gmail.com>
Sent: Saturday, July 19, 2025 5:41 PM
To: John Christy <climateman60@gmail.com>
Cc: Fisher, Travis <travis.fisher@hq.doe.gov>; roywspencer@hotmail.com; ross.mckitrick@gmail.com; Steve Koonin <steven.koonin@gmail.com>; Loucks, Joshua <Joshua.Loucks@hq.doe.gov>; Cohen, Seth <seth.cohen@hq.doe.gov>
Subject: Re: [EXTERNAL] Draft DOE report for review

My comments are attached, for the first 60% of the items included in Travis .doc file. I'll use red

On Sat, Jul 19, 2025 at 1:26 PM John Christy <climateman60@gmail.com> wrote:

All

For practice, I've entered my comments in the box where the reviewer had notes and references.

I CALL DIBS ON THE COLOR BLUE.

The spreadsheet gives me fits - it sometimes wraps text and sometimes it doesn't, so you often can't see the entry you just made. Editing in excel is not real fun either, but someone at DoE might make sense of this.

This is only a trial draft for me.

John C.

John Christy

Director, Earth System Science Center
Professor, Atmos and Earth Science
Alabama State Climatologist
The University of Alabama in Huntsville
climateman60@gmail.com

On Jul 19, 2025, at 3:19 PM, Fisher, Travis <travis.fisher@hq.doe.gov> wrote:

Hi Judy, the Excel version is the only version I have, but I have tried to move the comments into a Word doc. I am off to a wedding now, but I should be able to finish the conversion tomorrow. The attached file is my start. Does this format work better? Do you want me to include the citations when I finish tomorrow?

From: Judith Curry <curry.judith@gmail.com>
Sent: Saturday, July 19, 2025 3:46 PM
To: Fisher, Travis <travis.fisher@hq.doe.gov>
Cc: John Christy
<climateman60@gmail.com>; roywspencer@hotmail.com; ross.mckitrick@gmail.com; steven.koonin@gmail.com; Loucks, Joshua <Joshua.Loucks@hq.doe.gov>; Cohen, Seth <seth.cohen@hq.doe.gov>
Subject: Re: [EXTERNAL] Re: Draft DOE report for review

Travis, is there a .doc msword version of the review? I find this version fairly incomprehensible. I can copy text and try to make a msword doc out of this if such a version isn't available. Thanks

On Sat, Jul 19, 2025 at 10:53 AM Fisher, Travis <travis.fisher@hq.doe.gov> wrote:

Hi John,

Yes, I took every available precaution, including adding unique watermarks and password protection. I also admonished each reviewer to avoid even discussing the process with anyone outside of me, the reviewer, and the two members of the Office of Science who are helping me with the process.

Best,
Travis

From: John Christy <climateman60@gmail.com>
Sent: Saturday, July 19, 2025 11:47 AM
To: Fisher, Travis <travis.fisher@hq.doe.gov>
Cc: roywspencer@hotmail.com; curry.judith@gmail.com; ross.mckitrick@gmail.com; steven.koonin@gmail.com; Loucks, Joshua <Joshua.Loucks@hq.doe.gov>; Cohen, Seth <seth.cohen@hq.doe.gov>
Subject: [EXTERNAL] Re: Draft DOE report for review

Travis

Under the terms of this internal review, were reviewers informed that this was for-reviewer's-eyes only?

John C.

Sent from my iPhone

On Jul 19, 2025, at 10:32 AM, Fisher, Travis <travis.fisher@hq.doe.gov> wrote:

CWG members,

Attached is the first set of comments (the only set I've received so far). To generate a peer review report reflecting your resolution of these comments, we may want to keep your responses in a column adjacent to the reviewers' comments. I also anticipate being able to collate or combine comments, meaning we won't have to address eight separate rounds of comments. That said, I also plan to get these reviews to you as soon as I receive them so you have as much time as possible to digest them.

Also, please note that we have promised reviewers anonymity in terms of materials that face the public, but there's a chance that I accidentally leave personally identifiable info in the material I send to you. If that happens, please honor the anonymity of the reviewers—for many of them, that was a necessary condition for them to agree to the assignment.

Best,
Travis

<DOE Report Review 1.xlsx>

This message does not originate from a known Department of Energy email system. Use caution if this message contains attachments, links or requests for information.

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<image001.jpg>

Judith Curry, President
CFAN - Climate Forecast Applications Network
Reno, NV USA
curry.judith@cfanclimate.com | +1.404.803.2012
<http://www.cfanclimate.net>

<Review 1.docx>



Judith Curry, President
CFAN - Climate Forecast Applications Network
Reno, NV USA
curry.judith@cfanclimate.com | +1.404.803.2012
<http://www.cfanclimate.net>

CWG Report, Review 1

Comment on page viii, paragraph 2: The greening effect can't be due to increase in CO₂ alone. The fertilization effect needs Nitrogen and phosphorous. There is observational[1] evidence that nitrogen available to plants is decreasing with increasing CO₂ and thus acting to limit fertilization effect. Secondly, the greening of some portions of the planet are likely due to changes in precipitation patterns associated with changing climatic conditions and not entirely attributable to fertilization effect. We will also need to consider that the temperature effect on photosynthesis will also be a limiting mechanism to any continued greening due to fertilization in the future [2]. I recommend acknowledging that the greening is not attributable to CO₂ alone and continued greening in the future with increasing CO₂ is uncertain.

[1] Rachel E. Mason et al. Evidence, causes, and consequences of declining nitrogen availability in terrestrial ecosystems. *Science* 376, eabh3767(2022). DOI:10.1126/science.abh3767

[2] C.E. Moore, et al. The effect of increasing temperature on crop photosynthesis: from enzymes to ecosystems. *Exp. Bot.*, 72 (8) (2021), pp. 2822-2844

Response: See section 2.1 for a more detailed description

Comment on page viii, paragraph 3: I am glad we acknowledge that CO₂ causes warming, though I am not sure why we are not considering other energy sector related emissions that also cause warming (CFCs/HFCs, methane, aerosol effects). It is not clear what is meant by "CO₂ emissions have tended to overestimate observed trends". This is not correct, the cumulative emissions track the RCP8.5 scenario the closest [3,4]. While there was a decrease in emissions during the Covid-19 period the emissions are now back on track following RCP8.5. This statement should clarify what is meant by the statement in the text.

[3] C.R. Schwalm, S. Glendon, & P.B. Duffy, RCP8.5 tracks cumulative CO₂ emissions, *Proc. Natl. Acad. Sci. U.S.A.* 117 (33) 19656-19657, <https://doi.org/10.1073/pnas.2007117117> (2020).

[4] C.R. Schwalm, S. Glendon, & P.B. Duffy, Reply to Hausfather and Peters: RCP8.5 is neither problematic nor misleading, *Proc. Natl. Acad. Sci. U.S.A.* 117 (45) 27793-27794, <https://doi.org/10.1073/pnas.2018008117> (2020).

Response: I AGREE. TAKE OUT CO₂ EMISSIONS HAVE TENDED TO OVERESTIMATE OBSERVED TRENDS

Comment on page viii, paragraph 4: This paragraph seems to be talking about equilibrium climate sensitivity. The most recent model inter-comparison gives a wider range of climate sensitivities in the range of 1.8 to 5.7 and is wider than estimates of climate sensitivities that have been estimated from paleoclimatic and more recent historical datasets, in the range could

be in the range of 2.3 to 4.5 K[5]. The higher sensitivity in the most recent model assessments are an area of active investigation by modelers, the feasibility of a higher range needs to be confirmed with additional observational and process scale modeling [6]. The range for climate sensitivities, 1.8-2.7, should be corrected to the most recent findings, 2.3-4.5. We should also recognize that the (a)earth is a complex system of systems (b)we can't do an experiment to find out what is correct or reduced the uncertainty. As we get better at extracting temperature records and CO2 concentrations from paleo data, there will be better reconstructions and possibly narrower range along with improvements in modeling that resolve many physical, biological and chemical processes as we get to higher and cloud resolving spatial resolutions.

[5] Sherwood, S. C., Webb, M. J., Annan, J. D., Armour, K. C., Forster, P. M., Hargreaves, J. C., et al. (2020). An assessment of Earth's climate sensitivity using multiple lines of evidence. *Reviews of Geophysics*, 58, e2019RG000678. <https://doi.org/10.1029/2019RG000678>

[6] Zelinka, M. D., Myers, T. A., McCoy, D. T., Po-Chedley, S., Caldwell, P. M., Ceppi, P., et al. (2020). Causes of higher climate sensitivity in CMIP6 models. *Geophysical Research Letters*, 47, e2019GL085782. <https://doi.org/10.1029/2019GL085782>

Response: See Chapter 5 for detailed explanation of recent research on climate sensitivity that is cited in our report.

Comment on page viii, paragraph 5: This is again not true for the majority of the models in the AR6. Figure 7.19 in the IPCC AR6 report shows that majority of the models exhibit a range within the observational range. The models running hot in the most recent decades are the ones with climate sensitivities greater than 5K, which are 3 out of a total of 40 and it should be noted that about the same number of models also are running cold' compared to observed[7]

[7] Hausfather, Z., Drake, H. F., Abbott, T., & Schmidt, G. A. (2020). Evaluating the performance of past climate model projections. *Geophysical Research Letters*, 47, e2019GL085378. <https://doi.org/10.1029/2019GL085378>

Response: See Chapter 5 for a more detailed description and justification of our summary comment.

Comment on page viii, paragraphs 5,6,7: There is very little dispute that these are challenging issues for climate science. Many of the issues identified here related to compound effects (subsidence and sea-level rise; wildfire and forest management) that requires further scientific investigation. Identifying further research avenues/focus areas will be helpful to firm up some of the challenges faced in using the climate projections as discussed in the paragraph 9.

Response: There is no disagreement here.

Comment on page vii, paragraph 9: The focus on uncertainty is relevant and should be emphasized in future research. However, as a reasonable policy pathways, making decisions in the face of these uncertainties is critical. Most of the climate uncertainties that we have confidence at this time can be considered Level 2 and Level 3 uncertainties, approaches such as scenario analysis (and others) are suggested and followed for making hazard and risk estimates for future conditions. For deep uncertainty hazards (for example tornadoes etc.) that we don't have enough data or capability to model, developing methods for assessing the uncertainty and risk should be a focus of future research.

Response: There is no disagreement here.

Comment on page 2: The reason CO₂ was identified as a pollutant is the health consequences of increased temperature, flooding and other climate impacts and not because of any direct affect on health dur to exposure to atmospheric CO₂[8].

[8] <https://www.cdc.gov/climate-health/php/effects/index.html>

Response: There is no disagreement here.

Comment on page 3, chapter summary: The summary should note that CO₂ fertilization effects are limited by the availability of other critical plant nutrients (Nitrogen, Phosphorous). The fertilization effect is also constrained by higher temperature effecting photosynthesis[9]

[9] Xinyuan Wei et al 2025 Environ. Res. Lett. 20 064013

Response: This issue of nutrients is addressed in Chapter 9

Comment on page 3, paragraph 3: The attribution of greening to primarily CO₂ fertilization is questionable as per recent research. Specifically, in the Northern high latitudes (where the greening is most prominent), increases in temperatures due to climate change has been shown to provide the best explanation[10]. In the sub-Saharan region reforestation efforts and changing precipitation patterns lead to some of the observed greening (the great green wall) [11]. The attribution to CO₂ fertilization should be qualified by noting the other present and emerging constraints.

[10]Liu, J., Wennberg, P.O. An emergent constraint on the thermal sensitivity of photosynthesis and greenness in the high latitude northern forests. Sci Rep 14, 6189 (2024).
<https://doi.org/10.1038/s41598-024-56362-1>

[11] Francesco S.R. Pausata, Marco Gaetani, Gabriele Missouri, Alexis Berg, Danielle Maia de Souza, Rowan F. Sage, Peter B. deMenocal, The Greening of the Sahara: Past Changes and Future Implications, One Earth, Volume 2, Issue 3, 2020, Pages 235-250, ISSN 2590-3322,<https://doi.org/10.1016/j.oneear.2020.03.002>.

Response: ROSS

Comment on page 3, paragraph 5: This summarization ignores the compound effects of temperature, moisture and CO2 fertilization in assessing the impacts of CO2 increase on vegetation and crop yields. Many studies have shown that [12]. Making note of these compensating factors is required for a balanced view on CO2 fertilization effects on plants.

[12] Lesk, C., Anderson, W., Rigden, A. et al. Compound heat and moisture extreme impacts on global crop yields under climate change. Nat Rev Earth Environ 3, 872–889 (2022).
<https://doi.org/10.1038/s43017-022-00368-8>

Response: SENTENCE ADDED

Comment on page 4: Chen et al. (2024)[13] conclude that "In the attribution analysis of LAI trend and growth rate trend, there were some differences between multiple linear regression model and partial correlation analysis at high latitudes in the northern hemisphere. Partial correlation analysis showed that LAI trend and growth rate trend in this region were mainly affected by temperature and radiation, while multiple linear regression suggested that CO2 was the dominant driver. The results of the partial correlation analysis seem more reasonable because some previous studies have shown that vegetation change in the high latitudes of the northern Hemisphere is mainly positively affected by climate warming. Multiple linear regression model performed relatively poorly in this region and might not fully identify the contribution of individual drivers. In addition, our model does not include the contribution of land management, which has been highlighted in some previous studies. Of course, the contribution of land management to LAI trend and growth rate trend may be implied in other drivers, such as the positive contribution of CO2 to LAI trend in PP and PN areas".

[13] Xin Chen, Tiexi Chen, Bin He, Shuci Liu, Shengjie Zhou, Tingting Shi, The global greening continues despite increased drought stress since 2000, Global Ecology and Conservation, Volume 49, 2024, e02791,ISSN 2351-9894

Response: IS THIS WORTH REFERENCING?

Comment on page 5 (fig 2.2): A simple calculation will show us how misleading this figure is. It shows that over 600 Million years CO2 changed by around 6000ppm. That is a rate of change of 0.00001/yr; CO2 changed from 275 to 430 in the past 175 years, that is rate of change of 0.88ppm/yr. A change in the rate of over 10⁵ in magnitude - there in lies the problem. We are seeing a rapid increase in CO2 that has never been witnessed and the ecosystem and human society (which is at best 10K years old), may not be able to adapt to this rapid change.

Response: MAYBE WORTH ADDING A SENTENCE ABOUT RATE OF CHANGE?

Comment on page 6: This again suffers from not acknowledging the effects of compound and often compensating phenomena that is occurring with the on-going climate change. For example [14] note that much of the Midwest any benefit from CO₂ fertilization will be negated by temperature increases. [15] note that "Our results show that long-term physiological acclimation dampens the initial stimulation of plant net carbon assimilation to elevated [CO₂], and of plant water use to warming."

[14] Ursula M. Ruiz-Vera, Matthew Siebers, Sharon B. Gray, David W. Drag, David M. Rosenthal, Bruce A. Kimball, Donald R. Ort, Carl J. Bernacchi, Global Warming Can Negate the Expected CO₂ Stimulation in Photosynthesis and Productivity for Soybean Grown in the Midwestern United States , Plant Physiology, Volume 162, Issue 1, May 2013, Pages 410–423, <https://doi.org/10.1104/pp.112.211938>

[15] Lamba S, Hall M, Röntfors M, et al. Physiological acclimation dampens initial effects of elevated temperature and atmospheric CO₂ concentration in mature boreal Norway spruce. Plant Cell Environ. 2018; 41: 300–313. <https://doi.org/10.1111/pce.13079>

Response:

Comment on page 8: The fallacy of these arguments in terms of PH changes and evolution is that the changes described in this paragraph occurred over millennia and the evolutionary process had time to adapt; here with climate change we are talking about changes in our lifetime, the speed of change is the issue. This will lead to collapse of some ecosystem and by the time adaptation takes place it will be millions of years and in a different climate - not the one we have now and that enabled the rise of humans.

Response: SAME COMMENT AS the PAGE 5 comment?

Comment on page 12, chapter summary: The misuse of RCP8.5 as business as usual is acknowledged. However, this was never intended to be a no-policy or business as usual scenario but as a high-end baseline scenario. When dealing with interaction of physical systems with socio-economic projections (which tend to be highly uncertain and policy dependent), the development of this high baseline scenarios is intended to explore the uncertainty ranges that represent a high-end scenario[16,17]. As any engineer would acknowledge, this is a prudent approach when dealing with L3 and L4 type deep uncertainties and provide valid envelopes for assessing uncertainties and risks from high impact events/hazards. The rest of the statements here are uncertainties acknowledged by the climate scientists and included in developing projections and discussing the results[4]. Does the IPCC downplay the role of sun in climate change? The IPCC includes sun variability in all its assessments from the beginning and has been acknowledged as a potential but insignificant contributor.

[16] van Vuuren, D.P., Edmonds, J., Kainuma, M. et al. The representative concentration pathways: an overview. *Climatic Change* 109, 5 (2011). <https://doi.org/10.1007/s10584-011-0148-z>

[17] Hausfather, Z. (2025). An assessment of current policy scenarios over the 21st century and the reduced plausibility of high-emissions pathways. *Dialogues on Climate Change*, 2(1), 26-32. <https://doi.org/10.1177/29768659241304854> (Original work published 2025)

Response: Prudence requires giving little to no weight to implausible scenarios. Implausibility is not equivalent to very unlikely (e.g. 95th percentile), but rather includes impossible or implausible assumptions.

Comment on page 16: Please see above. The business-as-usual may be a misnomer but this is an 95% case that is typically included in any type of prudent uncertainty analysis, in particular given the difficulty of predicting the evolution of socio-economic and political conditions over the next 100 years. It should be noted the difference between RCP8.5 and RCP4.5 for mid-century conditions that is of particular focus for adaptation studies is not significant and most of the divergence in these two scenarios occurs later in the century.

Response: See previous response

Comment on page 19, paragraph 5: That the dynamic vegetation models need more development is acknowledged and is a defining challenge for Earth System Modeling for the next decade.

Response: There is no disagreement here

Comment on page 22, paragraph 3: As noted, Parker[18,19,20] has investigated the Urban effects on temperature records. The findings establish that by comparing warm and wind conditions world wide that the impact is negligible. However, as noted by authors, this literature hasn't progressed much over the last decade and much more attention needs to be paid to this question by employing newer models, datasets and analytical techniques available to us at present.

[18] Parker, D. Large-scale warming is not urban. *Nature* 432, 290 (2004). <https://doi.org/10.1038/432290a>

[19] Parker, D.E. (2010), Urban heat island effects on estimates of observed climate change. *WIREs Clim Change*, 1: 123-133. <https://doi.org/10.1002/wcc.21>.

[20] Parker, D. E., 2006: A Demonstration That Large-Scale Warming Is Not Urban. *J. Climate*, 19, 2882–2895, <https://doi.org/10.1175/JCLI3730.1>.

Response: The CWG Report addresses this concern.

Comment on page 28, paragraph 2: We can all agree that there is a desperate need for developing higher-resolution climate models that can get to cloud resolving scale so that we can represent the cloud feedbacks correctly in the model and avoid uncertainties from parameterization and scale dependency of the parameters. This doesn't make these models useless. The models provide directions for further improvements and necessary changes to reduce the uncertainty bands over the ECS.

Response: The models are useful for research purposes. The CWG Report demonstrates that they are not fit for the purpose of policy making.

Comment on page 29, paragraph 2: The databased approaches have mostly been robust with changes at the high end around 3-4C and at the low end around 1.8 to 2.5C as noted in the chapter. It will be challenging to make this range shorter given the data requirements and uncertainties in data over paleo/haloacene periods. It seems reasonable to estimate that we may have ECS in the range of 3 to 4K (higher than 3.5K being less likely [21]) at the higher end and this should not prevent us from planning and thinking on ways to prevent this possible scenario as it could have major consequences for humans across the planet.

[21] Michael Mann, Our Fragile Moment: How lessons from Earth's past can help us survive climate crisis, Hachette Group Inc., 2024.

Response: The Report acknowledges that 4C is a reasonable upper bound for the likely range

Comment on page 32, paragraph 3: The models range over a factor of three in ECS comparing the most sensitive to the least sensitive models. However vast majority of the models are in 3 to 3.5K sensitivity range and it is probably not correct to assign all models the same amount of importance, given the fact that some of institutes participating in the exercise have different levels of capacity to develop and test models.

Response: Some of the most reputable models have the highest values of ECS, including UK and US models. Only 5 of the models lie between 3 and 3.5C

Comment on page 34: While this analysis for the CMIP6 model set is accurate and focuses on a dataset that has shown higher ECS than previous iterations. it should be noted the models have exhibited considerable skill in predicting the subsequent GMST warming[22]. The criticism of the CMIP6 based high ECS models may be premature and probably will have to wait additional time before passing judgement. As noted in [22] these models have shown considerable skill when evaluated on their projections over the past 30-40 years after the projections were published.

[22] Hausfather, Z., Drake, H. F., Abbott, T., & Schmidt, G. A. (2020). Evaluating the performance of past climate model projections. *Geophysical Research Letters*, 47, e2019GL085378. <https://doi.org/10.1029/2019GL085378>

Response: Figure 5.3 in the Report clearly refutes this assertion

Comment on page 36: A recent study attributes the bias to inter-annual availability and residual bias in the satellite record. The pre- and post 2000 have temperature records from two separate satellites and the discrepancy in the trends needs to be resolved[23]

[23] Chung, ES., Kim, SJ., Sohn, BJ. et al. Multi-decadal climate variability and satellite biases have amplified model-observation discrepancies in tropical troposphere warming estimates. *Commun Earth Environ* 5, 342 (2024). <https://doi.org/10.1038/s43247-024-01510-8>

Response: Ref 23 is worth adding I think

The Chung et al. study (which did not go beyond 2014) confirms the models' too-high warming rates as well as documenting the shift in tropospheric temperatures of the RSS and UW datasets (which share very similar choice of satellites) relative to UAH and NOAA/STAR (which rely on empirical tests to determine when a satellite drifts too much). Christy et al. 2018 specifically examined the relative jump in RSS and UW datasets around 2000 finding that compared with other independent measures, the RSS and UW retain spurious warming from the aging NOAA-14 satellite. Thus the notion that satellite biases are an issue applies predominantly to RSS and UW. We agree that the timing of major events like ENSOs diminishes the fidelity of models to observations comparisons, but now with 46 years of record in Fig. 5.7, this concern is less valid. Be that as it may, CGW Fig. 5.7 is clear in noting all models overestimate the tropical temperature trend - even more positive than that of RSS and the two Reanalyses.

Comment on page 38, paragraph 3: This is challenge we need to face and work on improving the parametrizations. The new era of super high resolution models would resolve the complex interactions of turbulence, transport and clouds and will provide less uncertainty[24]. However, this can't be used to invalidate the entire set of models, the models are performing remarkably well given the complex system that is being modeled. It should be noted the models do cover the range of the observations and it is not outside the envelope of model predictions.

[24] Merlis, T. M., Guendelman, I., Cheng, K.-Y., Harris, L., Chen, Y.-T., Bretherton, C. S., et al. (2024). The vertical structure of tropical temperature change in global storm-resolving model simulations of climate change. *Geophysical Research Letters*, 51, e2024GL111549. <https://doi.org/10.1029/2024GL111549>

Response: The Report does not address invalidating the entire set of models. Rather we address the fitness-for-purpose of the models for policy making

Comment on page 40, paragraph 4: Part of the problem here may be which part of the stratosphere is sampled and the importance of interannual variabilities in the lower part of the stratosphere. [25] have shown that including the stratosphere as defined from 25 to 50km there is high confidence that the cooling signal caused by CO2 increase is detectable and beyond the noise levels of the natural and inter annual variability in the lowest part of the stratosphere. We should put this debate to rest.

[25] B.D. Santer, S. Po-Chedley, L. Zhao, C. Zou, Q. Fu, S. Solomon, D.W.J. Thompson, C. Mears, & K.E. Taylor, Exceptional stratospheric contribution to human fingerprints on atmospheric temperature, Proc. Natl. Acad. Sci. U.S.A. 120 (20) e2300758120, <https://doi.org/10.1073/pnas.2300758120> (2023).

Response: JOHN AND ROY? NEW SANTER PAPER NEEDS TO BE REFERENCED

Comment on page 42, paragraph 2: Given the large uncertainties in obtaining data over much of the Northern Hemisphere, using a smaller regional analysis to discount the models may be inappropriate. We should that this remains a question we need to resolve developing better datasets with more seasonal and sub-seasonal coverage to test the model on a global scale.

Response: This section directly addresses a region that is important to estimates of the Social Cost of Carbon in the context of agricultural productivity, again reiterating that the models are not fit for the purpose of policy making

Comment on page 44, paragraph 3: This statement from [26] refers to the fitness of global scale models to resolve regional scale features and argues for developing model at higher spatial resolutions. Using downscaling and other techniques additional insights can be gained at regional scales and provide information for a set of 'purposes'. However, we should work on getting to regional and local scales with GCM as quickly as possible.

[26] Cohn, T. A., and H. F. Lins (2005), Nature's style: Naturally trendy, Geophysics. Res. Lett., 32, L23402, doi:10.1029/2005GL024476.

Response:

Comment on page 47, paragraph 2: Looking for trends or estimating trends in extreme events in current and future climate is not necessarily an attribution study. Estimating frequency, duration and intensity of events helps understand the changing range of the hazard (if there is one). An attribution would be to find to what extent a particular event is influenced or affected by increase in CO2. I would consider these two not to be the same.

Response: The current model structural forms may not be adequate for resolving all of these issues merely by increasing spatial resolution

Comment on page 47, paragraph 3: Attributing any single event to changing climate is perilous, agreed.

Response:

Comment on page 47, paragraph 5: As noted by [26] there is not yet any strong evidence that LPT is a fact.

Response:

Comment on page 57, paragraph 2: I am not sure how one can conclude that the temperature extremes have decreased based on figure 6.3.4. If I understand correctly the Tmax-Tmin for each year was tabulated and a mean of this difference averaged over the 100+ years was subtracted from these values to get some thing like a anomaly. This anomaly seems to have moved from +3F to -3F over the course of q00 years and now trending upwards again. This suggests to me that there has been significant changes in the extremes over the years and the most recent trend is towards warmer highs?

Response: For each station and each year, the hottest day and coldest night are determined and their difference computed. These differences are then geographically averaged for the CONUS and then an overall average is removed to show the results as a type of anomaly. Reviewer 1 is correct, as indicated in the text, Tmin temperatures are almost universally rising more rapidly than Tmax, hence, the difference (or range) has declined overall. The flattening (or slight rise in the metric) in the past 20 years is clearly within the natural range, but does reveal an interesting stair-step pattern with rapid declines centered around the 1940's and 1990's and relatively flat periods in between. An explanation is under investigation, and a leading hypothesis is that there was rapid growth of manufactured surfaces around weather stations in the 1940s. Then, in the 1960s-80s many stations were re-located to relatively rural airports, which then experienced subsequent growth in manufactured surfaces around their weather stations in the 1990s. Thus, rapid nighttime warming in the 1940s and 1990s.

Comment on page 58, paragraph 3: The NCA5 is suggesting that the western US is experiencing increase in extreme heat (page 57, para 4); it seems like figure 6.3.5 establishes the fact and not contradict. There was no claim of pervasive (all CONUS) increase in the report.

Response:

Comment on page 59, paragraph 4: The definition of heat wave as consecutive 6 days seems to be a special case. The standard definition is exceedance of 85 or 90 percentile for 2 or more days. I can't check with NCA5 as it was taken down from the web.

Response: As correctly suggested by Reviewer 1, there are numerous ways to define a heat wave. CWG chose to follow one definition discussed in NCA4 (pg 191) and use 6 consecutive

days with Tmax > 90th percentile so to allow for consistent comparisons. However, changing the parameters will do little to alter the fundamental result that the 1920's to early 1950's contain the major heat wave events for the CONUS.

Comment on page 60, paragraphs 1,2: Figure 6.3.6 establishes that heatwaves as defined here have increased in the west and have shown increasing trend all over CONUS in the past 50 years. [27] shows the results for the last 60 years and there is little doubt that there is an increase over most of the CONUS, again the NCA5 report is off the web; figure 6.3.7 shows the heat waves are monotonically increasing from the 1960. Including the longer data is only interesting in the dust bowl 1930 camouflage the signal somewhat for the Midwest and central plains. The problem of taking averages over large regions (for example entire CONUS) is that it kills the peak signals and smooths out the emergent climate change indicators. Doing continental averages to look for extremes is really not very useful. Secondly, there is no particular reason to assume that the climate change signal (i.e. the number of heat waves) should showing up 100 years ago, as the CO2 in the atmosphere started to be of significance in the last 50 years.

[27] <https://www.epa.gov/climate-indicators/climate-change-indicators-heat-waves>

Response: As discussed in the CWG text, the EPA chart is (1) based on nighttime temperatures in the 50 largest US cities and (2) begins in 1961 which was the start of the coolest decade in over 100 years, thereby preconditioning the chart to have an upward trend. Urbanization is most clearly seen in nighttime temperature increases so this does not represent a change in the background climate, but more likely the local climates of cities. Rural areas show less nighttime warming. And avoiding earlier warm periods does not provide information on the larger scale of natural variability.

Comment on page 61, paragraph 4: averaged over all stations in the region, none of these trend parameters is statistically significant'. This is again how one would be looking at statistics of extremes in precipitation. As we know, precipitation is highly heterogeneous and location dependent. As observed there are trends even with the approaches chosen by the authors of this study compared to NCA5 and averaging that over and saying there is no trend seems disingenuous.

Response:

Comment on page 62, paragraph 2: same argument as above.

Response:

Comment on page 63 (box): again the issue here is that we are talking about events that are happening in a short-time and over a small region. Averaging over time and space and develop

statistics is probably not appropriate when we are talking about events such as the recent flooding event in Texas. If you average that event over 30 days, it will seem unremarkable.

Response: Extreme event totals are 1-day to 5-days depending on section discussed.

Comment on page 64, paragraph 1: As noted in NCA5 and shown in the analysis presented in figure 6.4.4 there is a clear trend of increase in extreme precipitation in 12 of the 27 stations analyzed. Again averaging over the entire region is not the best method for picking extreme precipitation events that are local both in time and space.

Response:

Comment on page 69, paragraph 2: However, there is evidence that flash droughts, which last weeks have increased over the Northeast and Midwest [28]

[28] Ronald D. Leeper, Rocky Bilotta, Bryan Petersen, Crystal J. Stiles, Richard Heim, Brian Fuchs, Olivier P. Prat, Michael Palecki, Steve Ansari

Response: The paper referenced by Reviewer 1 begins with data so recent (1999) that it cannot provide evidence for long-term changes in drought even though it suggests an increase in "flash droughts" over that period. Keep in mind, the DM is a product of subjective interpretation and objective measures - objective measures that have changed considerably during the past 25 years. (One of the CWG authors was an official contributor to the DM for 15 years.) One would wonder what would the 1920's, 30's and early 50's reveal if the DM was operational back then? A more consistent metric is provided in CWG Fig. 6.7.1.

Comment on page 70, paragraph 2: More recent analysis indicate forest loss due to wildfire accelerating over the recent past[29]. In particular there has been an increase in extreme fire radiative power with a 2 fold increase from 2003 to 2023 (period of satellite data availability)[30][31]. However, that these fires are not out-of-sample and there is a fire deficit as shown in figure 6.8.2 should be acknowledged. But this doesn't alleviate the concern that wildfire is leading to lot of socio-economic concerns and needs to be addressed[32].

[29] Tyukavina Alexandra , Potapov Peter , Hansen Matthew C. , Pickens Amy H. , Stehman Stephen V. , Turubanova Svetlana , Parker Diana , Zalles Viviana , Lima André , Kommareddy Indrani , Song Xiao-Peng , Wang Lei , Harris Nancy; Global Trends of Forest Loss Due to Fire From 2001 to 2019, Frontiers in Remote Sensing.Volume 3 – 2022,2022.

[30] Cunningham, C.X., Williamson, G.J. & Bowman, D.M.J.S. Increasing frequency and intensity of the most extreme wildfires on Earth. Nat Ecol Evol 8, 1420–1425 (2024).
<https://doi.org/10.1038/s41559-024-02452-2>

[31] Patrick H. Freeborn, W. Matt Jolly, Mark A. Cochrane, Gareth Roberts, Large wildfire driven increases in nighttime fire activity observed across CONUS from 2003–2020, *Remote Sensing of Environment*, Volume 268, 2022,12777

[32] Parks, S.A., Guiterman, C.H., Margolis, E.Q. et al. A fire deficit persists across diverse North American forests despite recent increases in area burned. *Nat Commun* 16, 1493 (2025). <https://doi.org/10.1038/s41467-025-56333-8>

Response:

Comment on page 71, paragraph 3: The question of forest management and its role on wildfire frequency and intensity is interesting and deserves further study.

Response:

Comment on page 80, paragraph 1: The global mean sea-level was increasing at a rate of 0.08 inches/yr in 1993 compared 0.18 inches/yr in 2023, almost double the rate[33], which is approximately what is needed to meet the NOAA projections by mid-century and seems plausible.

[33] Hamlington, B.D., Bellas-Manley, A., Willis, J.K. et al. The rate of global sea level rise doubled during the past three decades. *Commun Earth Environ* 5, 601 (2024). <https://doi.org/10.1038/s43247-024-01761-5>

Response:

Comment on page 88, paragraph 3: A possible reason the method used by IPCC (optimal fingerprinting) can be considered to address McKitnick criticism is in [34].

[34] Chen, H., Chen, S.X. & Mu, M. A statistical review on the optimal fingerprinting approach in climate change studies. *Clim Dyn* 62, 1439–1446 (2024). <https://doi.org/10.1007/s00382-023-06975-5>

Response:

Comment on page 92, paragraph 4: The role of clouds remains the single most uncertainty in climate modeling, I am glad this was acknowledged here.

Response:

Comment on page 93, paragraph 3: The substance of this paragraph was addressed in my comments in earlier sections. Some of the claims made here are either exaggerations of the usual practice (RCP8.5 being referred to as BAU) or the comment about not fit for purpose (a comment extracted from a publication that is calling out for cloud resolved models.

Response:

Comment on page 105, paragraphs 2,3,4,5: The problem with both the FACE studies and the soybean, Maize and wheat studies cited here are that they don't consider the effect of increase in temperature, changes in precipitation, humidity and other environmental factors along with CO₂ increases. These compound effects have been shown in wide number of studies [35] [36][37][38][39]. A meta analysis of the compound effects shows that increase in CO₂, along with temperature, precipitation changes effects the quality of the cereal and yields[40]. Another recent study evaluated the impacts on C3 and C4 crops and conclude that CO₂ enrichment for C3 crops could increase but will be compensated by temperature increase. CO₂ fertilization effect was found to be small for C4 [41]. It is important therefore that we consider the compound effects on crop yields and not just focus on CO₂ enrichment.

[35] Ruiz-Vera UM, Siebers M, Gray SB, Drag DW, Rosenthal DM, Kimball BA, Ort DR, Bernacchi CJ. Global warming can negate the expected CO₂ stimulation in photosynthesis and productivity for soybean grown in the Midwestern United States. *Plant Physiol.* 2013 May;162(1):410-23

[36] Levine LH, Richards JT, Wheeler RM. Super-elevated CO₂ interferes with stomatal response to ABA and night closure in soybean (*Glycine max*). *J Plant Physiol.* 2009 Jun 1;166(9):903-13.

[37] Večeřová K, Oravec M, Puranik S, Findurová H, Veselá B, Opoku E, Ofori-Amanfo KK, Klem K, Urban O, Sahu PP. Single and interactive effects of variables associated with climate change on wheat metabolome. *Front Plant Sci.* 2022 Oct 10;13:1002561.

[38] Thomas, J.M.G., Boote, K.J., Allen, L.H., Gallo-Meagher, M. and Davis, J.M. (2003), Elevated Temperature and Carbon Dioxide Effects on Soybean Seed Composition and Transcript Abundance. *Crop Sci.*, 43: 1548-1557. <https://doi.org/10.2135/cropsci2003.1548>

[39] Lesk, C., Anderson, W., Rigden, A. et al. Compound heat and moisture extreme impacts on global crop yields under climate change. *Nat Rev Earth Environ* 3, 872–889 (2022). <https://doi.org/10.1038/s43017-022-00368-8>

[40] Ben Mariem S, Soba D, Zhou B, Loladze I, Morales F, Aranjuelo I. Climate Change, Crop Yields, and Grain Quality of C3 Cereals: A Meta-Analysis of [CO₂], Temperature, and Drought Effects. *Plants.* 2021; 10(6):1052. <https://doi.org/10.3390/plants10061052>

[41] Rezaei, E.E., Webber, H., Asseng, S. et al. Climate change impacts on crop yields. *Nat Rev Earth Environ* 4, 831–846 (2023). <https://doi.org/10.1038/s43017-023-00491-0>

Response:

Comment on page 106, paragraph 1: Taylor and Schlenker 2021 also note that 'Climate change will likely have negative impact on agriculture in aggregate, especially in regions exposed to

extreme heat. And the CO₂-driven yield increases may be offset by effects on food nutrition and quality'. However, the results for US have been a net positive in the recent past but not true in the lower latitudes.

Response:

Comment on page 111, paragraphs 1,2: The criticism of NOAA Billion dollar map is likely warranted as it was never completely transparent how the data was generated. However, changing the baseline assumption and refactoring the data using a different set of criteria to make the effects smaller also doesn't make sense. We should continue collecting this data and make the data accessible for researchers and peer review. Figure 10.1 doesn't address these issues, it is another methodology with unknown provenance of the data.

Response:

Comment on page 117, paragraph 3: Climate change can be expected to increase cold weather extremes in regions that have not been exposed to these effects.

Response:

Comment on page 118, paragraph 3: The same Nobel prize winning model in its most recent study concludes that [42] "We conclude with three results relevant for climate policy. First, both current policies (base run) and the extended Paris Accord fall short of limiting global warming to 2 °C or to the cost–benefit optimal level. Second, the economic stakes in global climate policy are substantial, with estimated net present value of economic benefits around \$120 trillion from the cost–benefit optimal policy. Third, once differences in discounting are considered, the baseline DICE-2023 estimate of the social cost of carbon (\$66/tCO₂ for 2020) aligns closely with other recent estimates". Obviously this is the latest and the current version of the model and these results are quite different from those discussed on this page. These conclusions should also be included in this discussion to avoid selective reading of the literature.

[42] L. Barrage, & W. Nordhaus, Policies, projections, and the social cost of carbon: Results from the DICE-2023 model, Proc. Natl. Acad. Sci. U.S.A. 121 (13) e2312030121, <https://doi.org/10.1073/pnas.2312030121> (2024).

Response:

Comment on page 120, paragraph 1: Similar empirical studies [43] point to "Using an empirical approach that provides a robust lower bound on the persistence of impacts on economic growth, we find that the world economy is committed to an income reduction of 19% within the next 26 years independent of future emission choices (relative to a baseline without climate impacts, likely range of 11–29% accounting for physical climate and empirical uncertainty). These damages already outweigh the mitigation costs required to limit global warming to 2 °C

by sixfold over this near-term time frame and thereafter diverge strongly dependent on emission choices. Committed damages arise predominantly through changes in average temperature, but accounting for further climatic components raises estimates by approximately 50% and leads to stronger regional heterogeneity. Committed losses are projected for all regions except those at very high latitudes, at which reductions in temperature variability bring benefits. The largest losses are committed at lower latitudes in regions with lower cumulative historical emissions and lower present-day income". This study uses more of the daily temperature precipitation from 1600 hundred locations world wide instead of global means. There are numerous studies that show the cost, many described in the COP 21 and follow-on meetings.

[43] Kotz, M., Levermann, A. & Wenz, L. The economic commitment of climate change. *Nature* 628, 551–557 (2024). <https://doi.org/10.1038/s41586-024-07219-0>

Response:

Comment on page 130, paragraph 4: while small in terms of global emissions (just from the US transport sector), over period this will be significant reduction. We need to remember that US is the second highest emitter of CO₂.

From: Judith Curry <curry.judith@gmail.com>
Sent: Sunday, July 20, 2025 9:25 AM
To: John Christy
Cc: Fisher, Travis; roywspencer@hotmail.com; ross.mckitrick@gmail.com; Steve Koonin; Loucks, Joshua; Cohen, Seth
Subject: Re: [EXTERNAL] Draft DOE report for review

After thinking about the reviewers comments, I tend to agree with those re the Executive Summary. Propose rewritten first 4 paragraphs.

This report reviews scientific certainties and uncertainties in how anthropogenic carbon dioxide (CO₂) and other greenhouse gas emissions have affected, or will affect, the Nation's climate, extreme weather events, and selected metrics of societal well-being. Those emissions are increasing the concentration of CO₂ in the atmosphere through a complex and variable carbon cycle, where some portion of the additional CO₂ persists in the atmosphere for centuries. ARE WE FOCUSING ONLY ON CO2 OR ALL GHG.

Elevated concentrations of CO₂ directly enhance plant growth, globally contributing to "greening" the planet and increasing agricultural productivity. They also make the oceans less alkaline (lower the pH) by an amount within the range of natural variability. That is possibly detrimental to coral reefs, although the recent rebound of the Great Barrier Reef suggests otherwise. COMBINE PARA Carbon dioxide also acts as a greenhouse gas, exerting a warming influence on climate and weather. Scenarios of future CO₂ emissions have tended to overestimate observed levels. WE ASSERT THIS REFERRING TO RM PAPERS. IGNORE A LOT OF OTHER PAPERS SAYING THE OPPOSITE. WE DON'T NEED THIS STATEMENT. DEF NOT IN SUMMARY

The world's several dozen detailed global climate models offer little guidance on how much the climate responds to elevated CO₂, with the average surface warming under a doubling of the CO₂ concentration ranging from 1.8°C to 5.7°C, a larger range than data driven estimates that suggest a response in the range 1.8°C to 2.7°C. COMBINE PARA Detailed Global climate models also generally run "hot" in their description of the climate of the past few decades show too much warming at the surface and too much amplification of warming in the lower- and mid-troposphere. They also produce too much stratospheric cooling and too much snow loss. ONLY REFERS TO US and too much warming in the U.S. Corn Belt. ODD THING TO MENTION WITHOUT CONTEXT The combination of overly sensitive models and implausible extreme scenarios for future emissions has exaggerated projections of future warming.

Most extreme weather events do not show long-term trends. Claims of increased frequency or intensity of hurricanes, tornadoes, floods, and droughts are not supported by U.S. historical data. Additionally, forest management practices are often overlooked in assessing changes in wildfire activity. Global sea level has risen approximately 8 inches since 1900, but there are significant regional variations in tide gauge data driven primarily by local land subsidence; U.S. tide gauge measurements in aggregate show no obvious acceleration in sea level rise beyond the historical average rate.

On Sat, Jul 19, 2025 at 2:40 PM Judith Curry <curry.judith@gmail.com> wrote:

My comments are attached, for the first 60% of the items included in Travis .doc file. I'll use red

On Sat, Jul 19, 2025 at 1:26 PM John Christy <climateman60@gmail.com> wrote:

All

For practice, I've entered my comments in the box where the reviewer had notes and references.

I CALL DIBS ON THE COLOR BLUE.

The spreadsheet gives me fits - it sometimes wraps text and sometimes it doesn't, so you often can't see the entry you just made. Editing in excel is not real fun either, but someone at DoE might make sense of this.

This is only a trial draft for me.

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John Christy
Director, Earth System Science Center
Professor, Atmos and Earth Science
Alabama State Climatologist
The University of Alabama in Huntsville
climateman60@gmail.com

On Jul 19, 2025, at 3:19 PM, Fisher, Travis <travis.fisher@hq.doe.gov> wrote:

Hi Judy, the Excel version is the only version I have, but I have tried to move the comments into a Word doc. I am off to a wedding now, but I should be able to finish the conversion tomorrow. The attached file is my start. Does this format work better? Do you want me to include the citations when I finish tomorrow?

From: Judith Curry <curry.judith@gmail.com>

Sent: Saturday, July 19, 2025 3:46 PM

To: Fisher, Travis <travis.fisher@hq.doe.gov>

Cc: John Christy

<climateman60@gmail.com>; roywspencer@hotmail.com; ross.mckitrick@gmail.com; steven.koonin@gmail.com; Loucks, Joshua <Joshua.Loucks@hq.doe.gov>; Cohen, Seth <seth.cohen@hq.doe.gov>

Subject: Re: [EXTERNAL] Re: Draft DOE report for review

Travis, is there a .doc msword version of the review? I find this version fairly incomprehensible. I can copy text and try to make a msword doc out of this if such a version isn't available. Thanks

On Sat, Jul 19, 2025 at 10:53 AM Fisher, Travis <travis.fisher@hq.doe.gov> wrote:

Hi John,

Yes, I took every available precaution, including adding unique watermarks and password protection. I also admonished each reviewer to avoid even discussing the process with anyone outside of me, the reviewer, and the two members of the Office of Science who are helping me with the process.

Best,
Travis

From: John Christy <climateman60@gmail.com>
Sent: Saturday, July 19, 2025 11:47 AM
To: Fisher, Travis <travis.fisher@hq.doe.gov>
Cc: roywspencer@hotmail.com; curry.judith@gmail.com; ross.mckitrick@gmail.com; steven.koonin@gmail.com; Loucks, Joshua <Joshua.Loucks@hq.doe.gov>; Cohen, Seth <seth.cohen@hq.doe.gov>
Subject: [EXTERNAL] Re: Draft DOE report for review

Travis

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John C.

Sent from my iPhone

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Judith Curry, President
CFAN - Climate Forecast Applications Network
Reno, NV USA
curry.judith@cfanclimate.com | +1.404.803.2012
<http://www.cfanclimate.net>

<Review 1.docx>

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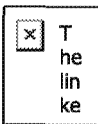
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CFAN - Climate Forecast Applications
Network
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curry.judith@cfanclimate.com |
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Judith Curry, President
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Network
Reno, NV USA
curry.judith@cfanclimate.com |
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CWG Report, Review 1

Comment on page viii, paragraph 2: The greening effect can't be due to increase in CO2 alone. The fertilization effect needs Nitrogen and phosphorous. There is observational[1] evidence that nitrogen available to plants is decreasing with increasing CO2 and thus acting to limit fertilization effect. Secondly, the greening of some portions of the planet are likely due to changes in precipitation patterns associated with changing climatic conditions and not entirely attributable to fertilization effect. We will also need to consider that the temperature effect on photosynthesis will also be a limiting mechanism to any continued greening due to fertilization in the future [2]. I recommend acknowledging that the greening is not attributable to CO2 alone and continued greening in the future with increasing CO2 is uncertain.

Response: See section 2.1 for a more detailed description

Comment on page viii, paragraph 3: I am glad we acknowledge that CO2 causes warming, though I am not sure why we are not considering other energy sector related emissions that also cause warming (CFCs/HFCs, methane, aerosol effects). It is not clear what is meant by "CO2 emissions have tended to overestimate observed trends". This is not correct, the cumulative emissions track the RCP8.5 scenario the closest [3,4]. While there was a decrease in emissions during the Covid-19 period the emissions are now back on track following RCP8.5. This statement should clarify what is meant by the statement in the text.

Response: I AGREE. TAKE OUT CO2 EMISSIONS HAVE TENDED TO OVERESTIMATE OBSERVED TRENDS

Comment on page viii, paragraph 4: This paragraph seems to be talking about equilibrium climate sensitivity. The most recent model inter-comparison gives a wider range of climate sensitivities in the range of 1.8 to 5.7 and is wider than estimates of climate sensitivities that have been estimated from paleoclimatic and more recent historical datasets, in the range could be in the range of 2.3 to 4.5 K[5]. The higher sensitivity in the most recent model assessments are an area of active investigation by modelers, the feasibility of a higher range needs to be confirmed with additional observational and process scale modeling [6]. The range for climate sensitivities, 1.8-2.7, should be corrected to the most recent findings, 2.3-4.5. We should also recognize that the (a)earth is a complex system of systems (b)we can't do an experiment to find out what is correct or reduced the uncertainty. As we get better at extracting temperature records and CO2 concentrations from paleo data, there will be better reconstructions and possibly narrower range along with improvements in modeling that resolve many physical, biological and chemical processes as we get to higher and cloud resolving spatial resolutions.

Response: See Chapter 5 for detailed explanation of recent research on climate sensitivity that is cited in our report.

Comment on page viii, paragraph 5: This is again not true for the majority of the models in the AR6. Figure 7.19 in the IPCC AR6 report shows that majority of the models exhibit a range within the observational range. The models running hot in the most recent decades are the ones with climate sensitivities greater than 5K, which are 3 out of a total of 40 and it should be noted that about the same number of models also are running cold' compared to observed[7]

Response: See Chapter 5 for a more detailed description and justification of our summary comment.

Comment on page viii, paragraphs 5,6,7: There is very little dispute that these are challenging issues for climate science. Many of the issues identified here related to compound effects (subsidence and sea-level rise; wildfire and forest management) that requires further scientific investigation. Identifying further research avenues/focus areas will be helpful to firm up some of the challenges faced in using the climate projections as discussed in the paragraph 9.

Response: There is no disagreement here.

Comment on page vii, paragraph 9: The focus on uncertainty is relevant and should be emphasized in future research. However, as a reasonable policy pathways, making decisions in the face of these uncertainties is critical. Most of the climate uncertainties that we have confidence at this time can be considered Level 2 and Level 3 uncertainties, approaches such as scenario analysis (and others) are suggested and followed for making hazard and risk estimates for future conditions. For deep uncertainty hazards (for example tornadoes etc.) that we don't have enough data or capability to model, developing methods for assessing the uncertainty and risk should be a focus of future research.

Response: There is no disagreement here.

Comment on page 2: The reason CO2 was identified as a pollutant is the health consequences of increased temperature, flooding and other climate impacts and not because of any direct affect on health due to exposure to atmospheric CO2[8].

Response: There is no disagreement here.

Comment on page 3, chapter summary: The summary should note that CO2 fertilization effects are limited by the availability of other critical plant nutrients (Nitrogen, Phosphorous). The fertilization effect is also constrained by higher temperature affecting photosynthesis[9]

Response: This issue of nutrients is addressed in Chapter 9

Comment on page 3, paragraph 3: The attribution of greening to primarily CO2 fertilization is questionable as per recent research. Specifically, in the Northern high latitudes (where the greening is most prominent), increases in temperatures due to climate change has been shown

to provide the best explanation[10]. In the sub-Saharan region reforestation efforts and changing precipitation patterns lead to some of the observed greening (the great green wall) [11]. The attribution to CO2 fertilization should be qualified by noting the other present and emerging constraints.

Response: ROSS

Comment on page 3, paragraph 5: This summarization ignores the compound effects of temperature, moisture and CO2 fertilization in assessing the impacts of CO2 increase on vegetation and crop yields. Many studies have shown that [12]. Making note of these compensating factors is required for a balanced view on CO2 fertilization effects on plants.

Response: SENTENCE ADDED

Comment on page 4: Chen et al. (2024)[13] conclude that "In the attribution analysis of LAI trend and growth rate trend, there were some differences between multiple linear regression model and partial correlation analysis at high latitudes in the northern hemisphere. Partial correlation analysis showed that LAI trend and growth rate trend in this region were mainly affected by temperature and radiation, while multiple linear regression suggested that CO2 was the dominant driver. The results of the partial correlation analysis seem more reasonable because some previous studies have shown that vegetation change in the high latitudes of the northern Hemisphere is mainly positively affected by climate warming. Multiple linear regression model performed relatively poorly in this region and might not fully identify the contribution of individual drivers. In addition, our model does not include the contribution of land management, which has been highlighted in some previous studies. Of course, the contribution of land management to LAI trend and growth rate trend may be implied in other drivers, such as the positive contribution of CO2 to LAI trend in PP and PN areas".

Response: IS THIS WORTH REFERENCING?

Comment on page 5 (fig 2.2): A simple calculation will show us how misleading this figure is. It shows that over 600 Million years CO2 changed by around 6000ppm. That is a rate of change of 0.00001/yr; COE changed from 275 to 430 in the past 175 years, that is rate of change of 0.88ppm/yr. A change in the rate of over 10⁵ in magnitude - there in lies the problem. We are seeing a rapid increase in CO2 that has never been witnessed and the ecosystem and human society (which is at best 10K years old), may not be able to adapt to this rapid change.

Response: MAYBE WORTH ADDING A SENTENCE ABOUT RATE OF CHANGE?

Comment on page 6: This again suffers from not acknowledging the effects of compound and often compensating phenomena that is occurring with the on-going climate change. For example [14] note that much of the Midwest any benefit from CO2 fertilization will be negated

by temperature increases. [15] note that "Our results show that long-term physiological acclimation dampens the initial stimulation of plant net carbon assimilation to elevated [CO₂], and of plant water use to warming."

Response:

Comment on page 8: The fallacy of these arguments in terms of PH changes and evolution is that the changes described in this paragraph occurred over millennia and the evolutionary process had time to adapt; here with climate change we are talking about changes in our lifetime, the speed of change is the issue. This will lead to collapse of some ecosystem and by the time adaptation takes place it will be millions of years and in a different climate - not the one we have now and that enabled the rise of humans.

Response: SAME COMMENT AS the PAGE 5 comment?

Comment on page 12, chapter summary: The misuse of RCP8.5 as business as usual is acknowledged. However, this was never intended to be a no-policy or business as usual scenario but as a high-end baseline scenario. When dealing with interaction of physical systems with socio-economic projections (which tend to be highly uncertain and policy dependent), the development of this high baseline scenarios is intended to explore the uncertainty ranges that represent a high-end scenario[16,17]. As any engineer would acknowledge, this is a prudent approach when dealing with L3 and L4 type deep uncertainties and provide valid envelopes for assessing uncertainties and risks from high impact events/hazards. The rest of the statements here are uncertainties acknowledged by the climate scientists and included in developing projections and discussing the results[4]. Does the IPCC downplay the role of sun in climate change? The IPCC includes sun variability in all its assessments from the beginning and has been acknowledged as a potential but insignificant contributor.

Response: Prudence requires giving little to no weight to implausible scenarios. Implausibility is not equivalent to very unlikely (e.g. 95th percentile), but rather includes impossible or implausible assumptions.

Comment on page 16: Please see above. The business-as-usual may be a misnomer but this is an 95% case that is typically included in any type of prudent uncertainty analysis, in particular given the difficulty of predicting the evolution of socio-economic and political conditions over the next 100 years. It should be noted the difference between RCP8.5 and RCP4.5 for mid-century conditions that is of particular focus for adaptation studies is not significant and most of the divergence in these two scenarios occurs later in the century.

Response: See previous response

Comment on page 19, paragraph 5: That the dynamic vegetation models need more development is acknowledged and is a defining challenge for Earth System Modeling for the next decade.

Response: There is no disagreement here

Comment on page 22, paragraph 3: As noted, Parker[18,19,20] has investigated the Urban effects on temperature records. The finding establish that by comparing warm and wind conditions world wide that the impact is negligible. However, as noted by authors, this literature hasn't progressed much over the last decade and much more attention needs to be paid to this question by employing newer models, datasets and analytical techniques available to us at present.

Response: The CWG Report addresses this concern.

Comment on page 28, paragraph 2: We can all agree that there is a desperate need for developing higher-resolution climate models that can get to cloud resolving scale so that we can represent the cloud feedbacks correctly in the model and avoid uncertainties from parameterization and scale dependency of the parameters. This doesn't make these models useless. The models provide directions for further improvements and necessary changes to reduce the uncertainty bands over the ECS.

Response: The models are useful for research purposes. The CWG Report demonstrates that they are not fit for the purpose of policy making.

Comment on page 29, paragraph 2: The databased approaches have mostly been robust with changes at the high end around 3-4C and at the low end around 1.8 to 2.5C as noted in the chapter. It will be challenging to make this range shorter given the data requirements and uncertainties in data over paleo/haloocene periods. It seems reasonable to estimate that we may have ECS in the range of 3 to 4K (higher than 3.5K being less likely [21]) at the higher end and this should not prevent us from planning and thinking on ways to prevent this possible scenario as it could have major consequences for humans across the planet.

Response: The Report acknowledges that 4C is a reasonable upper bound for the likely range

Comment on page 32, paragraph 3: The models range over a factor of three in ECS comparing the most sensitive to the least sensitive models. However vast majority of the models are in 3 to 3.5K sensitivity range and it is probably not correct to assign all models the same amount of importance, given the fact that some of institutes participating in the exercise have different levels of capacity to develop and test models.

Response: Some of the most reputable models have the highest values of ECS, including UK and US models. Only 5 of the models lie between 3 and 3.5C

Comment on page 34: While this analysis for the CMIP6 model set is accurate and focuses on a dataset that has shown higher ECS than previous iterations. it should be noted the models have exhibited considerable skill in predicting the subsequent GMST warming[22]. The criticism of the CMIP6 based high ECS models may be premature and probably will have to wait additional time before passing judgement. As noted in [22] these models have shown considerable skill when evaluated on their projections over the past 30-40 years after the projections were published.

Response: Figure 5.3 in the Report clearly refutes this assertion

Comment on page 36: A recent study attributes the bias to inter-annual availability and residual bias in the satellite record. The pre- and post 2000 have temperature records from two separate satellites and the discrepancy in the trends needs to be resolved[23]

Response: Ref 23 is worth adding I think

Comment on page 38, paragraph 3: This is challenge we need to face and work on improving the parametrizations. The new era of super high resolution models would resolve the complex interactions of turbulence, transport and clouds and will provide less uncertainty[24]. However, this can't be used to invalidate the entire set of models, the models are performing remarkably well given the complex system that is being modeled. It should be noted the models do cover the range of the observations and it is not outside the envelope of model predictions.

Response: The Report does not address invalidating the entire set of models. Rather we address the fitness-for-purpose of the models for policy making

Comment on page 40, paragraph 4: Part of the problem here may be which part of the stratosphere is sampled and the importance of interannual a variabilities in the lower part of the stratosphere. [25] have shown that including the stratosphere as defined from 25 to 50km there is high confidence that the cooling signal caused by CO2 increase is detectable and beyond the noise levels of the natural and inter annual variability in the lowest part of the stratosphere. We should put this debate to rest.

Response: JOHN AND ROY? NEW SANTER PAPER NEEDS TO BE REFERENCED

Comment on page 42, paragraph 2: Given the large uncertainties in obtaining data over much of the Northern Hemisphere, using a smaller regional analysis to discount the models may be inappropriate. We should that this remains a question we need to resolve developing better datasets with more seasonal and sub-seasonal coverage to test the model on a global scale.

Response: This section directly addresses a region that is important to estimates of the Social Cost of Carbon in the context of agricultural productivity, again reiterating that the models are not fit for the purpose of policy making

Comment on page 44, paragraph 3: This statement from [26] refers to the fitness of global scale models to resolve regional scale features and argues for developing model at higher spatial resolutions. Using downscaling and other techniques additional insights can be gained at regional scales and provide information for a set of 'purposes'. However, we should work on getting to regional and local scales with GCM as quickly as possible.

Response: The current model structural forms may not be adequate for resolving all of these issues merely by increasing spatial resolution

Comment on page 47, paragraph 2:

From: Judith Curry <curry.judith@gmail.com>
Sent: Saturday, July 19, 2025 4:43 PM
To: John Christy
Cc: Fisher, Travis; roywspencer@hotmail.com; ross.mckitrick@gmail.com; Steve Koonin; Loucks, Joshua; Cohen, Seth
Subject: Re: [EXTERNAL] Draft DOE report for review

John, good comments, but as for moi, i am waiting on a msword .doc version to add comments

On Sat, Jul 19, 2025 at 1:26 PM John Christy <climateman60@gmail.com> wrote:

All

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I CALL DIBS ON THE COLOR BLUE.

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The University of Alabama in Huntsville
climateman60@gmail.com

On Jul 19, 2025, at 3:19 PM, Fisher, Travis <travis.fisher@hq.doe.gov> wrote:

Hi Judy, the Excel version is the only version I have, but I have tried to move the comments into a Word doc. I am off to a wedding now, but I should be able to finish the conversion tomorrow. The attached file is my start. Does this format work better? Do you want me to include the citations when I finish tomorrow?

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Cc: John Christy
<climateman60@gmail.com>; roywspencer@hotmail.com; ross.mckitrick@gmail.com; steven.koonin@

gmail.com; Loucks, Joshua <Joshua.Loucks@hq.doe.gov>; Cohen, Seth <seth.cohen@hq.doe.gov>

Subject: Re: [EXTERNAL] Re: Draft DOE report for review

Travis, is there a .doc msword version of the review? I find this version fairly incomprehensible. I can copy text and try to make a msword doc out of this if such a version isn't available. Thanks

On Sat, Jul 19, 2025 at 10:53 AM Fisher, Travis <travis.fisher@hq.doe.gov> wrote:

Hi John,

Yes, I took every available precaution, including adding unique watermarks and password protection. I also admonished each reviewer to avoid even discussing the process with anyone outside of me, the reviewer, and the two members of the Office of Science who are helping me with the process.

Best,
Travis

From: John Christy <climateman60@gmail.com>

Sent: Saturday, July 19, 2025 11:47 AM

To: Fisher, Travis <travis.fisher@hq.doe.gov>

Cc: roywspencer@hotmail.com; curry.judith@gmail.com; ross.mckitrick@gmail.com; steven.koonin@gmail.com; Loucks, Joshua <Joshua.Loucks@hq.doe.gov>; Cohen, Seth <seth.cohen@hq.doe.gov>

Subject: [EXTERNAL] Re: Draft DOE report for review

Travis

Under the terms of this internal review, were reviewers informed that this was for-reviewer's-eyes only?

John C.

Sent from my iPhone

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CWG members,

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Also, please note that we have promised reviewers anonymity in terms of materials that face the public, but there's a chance that I accidentally leave personally identifiable info in the material I send to you. If that happens, please honor the anonymity of the reviewers—for many of them, that was a necessary condition for them to agree to the assignment.

Best,
Travis

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Judith Curry, President
CFAN - Climate Forecast Applications Network
Reno, NV USA
curry.judith@cfanclimate.com | +1.404.803.2012
<http://www.cfanclimate.net>

<Review 1.docx>

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Loucks, Joshua <Joshua.Loucks@hq.doe.gov <<mailto:Joshua.Loucks@hq.doe.gov>>>; Cohen, Seth <seth.cohen@hq.doe.gov
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> *****
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> <image001.jpg>
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US emission policies

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Comment or Suggested Edit

The greening effect can't be due to increase in CO₂ alone. The fertilization effect needs Nitrogen and phosphorous. There is observational[1] evidence that nitrogen available to plants is decreasing with increasing CO₂ and thus acting to limit fertilization effect. Secondly, the greening of some portions of the planet are likely due to changes in precipitation patterns associated with changing climatic conditions and not entirely attributable to fertilization effect. We will also need to consider that the temperature effect on photosynthesis will also be a limiting mechanism to any continued greening due to fertilization in the future [2]. I recommend acknowledging that the greening is not attributable to CO₂ alone and continued greening in the future with increasing CO₂ is uncertain.

I am glad we acknowledge that CO₂ causes warming, though I am not sure why we are not considering other energy sector related emissions that also cause warming (CFCs/HFCs, methane, aerosol effects). It is not clear what is meant by "CO₂ emissions have tended to overestimate observed trends". This is not correct, the cumulative emissions track the RCP8.5 scenario the closest [3,4]. While there was a decrease in emissions during the Covid-19 period the emissions are now back on track following RCP8.5. This statement should clarify what is meant by the statement in the text.

This paragraph seems to be talking about equilibrium climate sensitivity. The most recent model inter-comparison gives a wider range of climate sensitivities in the range of 1.8 to 5.7 and is wider than estimates of climate sensitivities that have been estimated from paleoclimatic and more recent historical datasets, in the range could be in the range of 2.3 to 4.5 K[5]. The higher sensitivity in the most recent model assessments are an area of active investigation by modelers, the feasibility of a higher range needs to be confirmed with additional observational and process scale modeling [6]. The range for climate sensitivities, 1.8-2.7, should be corrected to the most recent findings, 2.3-4.5. We should also recognize that the (a)earth is a complex system of systems (b)we can't do an experiment to find out what is correct or reduced the uncertainty. As we get better at extracting temperature records and CO₂ concentrations from paleo data, there will be better reconstructions and possibly narrower range along with improvements in modeling that resolve many physical, biological and chemical processes as we get to higher and cloud resolving spatial resolutions.

This is again not true for the majority of the models in the AR6. Figure 7.19 in the IPCC AR6 report shows that majority of the models exhibit a range within the observational range. The models running hot in the most recent decades are the ones with climate sensitivities greater than 5K, which are 3 out of a total of 40 and it should be noted that about the same number of models also are running cold' compared to observed[7]

There is very little dispute that these are challenging issues for climate science. Many of the issues identified here related to compound effects (subsidence and sea-level rise; wildfire and forest management) that requires further scientific investigation. Identifying further research avenues/focus areas will be helpful to firm up some of the challenges faced in using the climate projections as discussed in the paragraph 9.

The focus on uncertainty is relevant and should be emphasized in future research. However, as a reasonable policy pathways, making decisions in the face of these uncertainties is critical. Most of the climate uncertainties that we have confidence at this time can be considered Level 2 and Level 3 uncertainties, approaches such as scenario analysis (and others) are suggested and followed for making hazard and risk estimates for future conditions. For deep uncertainty hazards (for example tornadoes etc.) that we don't have enough data or capability to model, developing methods for assessing the uncertainty and risk should be a focus of future research.

The reason CO₂ was identified as a pollutant is the health consequences of increased temperature, flooding and other climate impacts and not because of any direct affect on health due to exposure to atmospheric CO₂[8].

The summary should note that CO₂ fertilization effects are limited by the availability of other critical plant nutrients (Nitrogen, Phosphorous). The fertilization effect is also constrained by higher temperature effecting photosynthesis[9]

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Chen et al. (2024)[13] conclude that "In the attribution analysis of LAI trend and growth rate trend, there were some differences between multiple linear regression model and partial correlation analysis at high latitudes in the northern hemisphere. Partial correlation analysis showed that LAI trend and growth rate trend in this region were mainly affected by temperature and radiation, while multiple linear regression suggested that CO₂ was the dominant driver. The results of the partial correlation analysis seem more reasonable because some previous studies have shown that vegetation change in the high latitudes of the northern Hemisphere is mainly positively affected by climate warming. Multiple linear regression model performed relatively poorly in this region and might not fully identify the contribution of individual drivers. In addition, our model does not include the contribution of land management, which has been highlighted in some previous studies. Of course, the contribution of land management to LAI trend and growth rate trend may be implied in other drivers, such as the positive contribution of CO₂ to LAI trend in PP and PN areas".

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A simple calculation will show us how misleading this figure is. It shows that over 600 Million years CO₂ changed by around 6000ppm. That is a rate of change of 0.00001/yr; CO₂ changed from 275 to 430 in the past 175 years, that is rate of change of 0.88ppm/yr. A change in the rate of over 10⁵ in magnitude - there in lies the problem. We are seeing a rapid increase in CO₂ that has never been witnessed and the ecosystem and human society (which is at best 10K years old), may not be able to adapt to this rapid change.

The misuse of RCP8.5 as business as usual is acknowledged. However, this was never intended to be a no-policy or business as usual scenario but as a high-end baseline scenario. When dealing with interaction of physical systems with socio-economic projections (which tend to be highly uncertain and policy dependent), the development of this high baseline scenarios is intended to explore the uncertainty ranges that represent a high-end scenario[16,17]. As any engineer would acknowledge, this is a prudent approach when dealing with L3 and L4 type deep uncertainties and provide valid envelopes for assessing uncertainties and risks from high impact events/hazards. The rest of the statements here are uncertainties acknowledged by the climate scientists and included in developing projections and discussing the results[4]. Does the IPCC downplay the role of sun in climate change? The IPCC includes sun variability in all its assessments from the beginning and has been acknowledged as a potential but insignificant contributor.

Please see above. The business-as-usual may be a misnomer but this is an 95% case that is typically included in any type of prudent uncertainty analysis, in particular given the difficulty of predicting the evolution of socio-economic and political conditions over the next 100 years. It should be noted the difference between RCP8.5 and RCP4.5 for mid-century conditions that is of particular focus for adaptation studies is not significant and most of the divergence in these two scenarios occurs later in the century. That the dynamic vegetation models need more development is acknowledged and is a defining challenge for Earth System Modeling for the next decade.

As noted, Parker[18,19,20] has investigated the Urban effects on temperature records. The finding establish that by comparing warm and wind conditions world wide that the impact is negligible. However, as noted by authors, this literature hasn't progressed much over the last decade and much more attention needs to be paid to this question by employing newer models, datasets and analytical techniques available to us at present.

We can all agree that there is a desperate need for developing higher-resolution climate models that can get to cloud resolving scale so that we can represent the cloud feedbacks correctly in the model and avoid uncertainties from parameterization and scale dependency of the parameters. This doesn't make these models useless. The models provide directions for further improvements and necessary changes to reduce the uncertainty bands over the ECS.

The databased approaches have mostly been robust with changes at the high end around 3-4C and at the low end around 1.8 to 2.5C as noted in the chapter. It will be challenging to make this range shorter given the data requirements and uncertainties in data over paleo/haloacene periods. It seems reasonable to estimate that we may have ECS in the range of 3 to 4K (higher than 3.5K being less likely [21]) at the higher end and this should not prevent us from planning and thinking on ways to prevent this possible scenario as it could have major consequences for humans across the planet.

The models range over a factor of three in ECS comparing the most sensitive to the least sensitive models. However vast majority of the models are in 3 to 3.5K sensitivity range and it is probably not correct to assign all models the same amount of importance, given the fact that some of institutes participating in the exercise have different levels of capacity to develop and test models.

While this analysis for the CMIP6 model set is accurate and focuses on a dataset that has shown higher ECS than previous iterations. it should be noted the models have exhibited considerable skill in predicting the subsequent GMST warming[22]. The criticism of the CMIP6 based high ECS models may be premature and probably will have to wait additional time before passing judgement. As noted in [22] these models have shown considerable skill when evaluated on their projections over the past 30-40 years after the projections were published.

A recent study attributes the bias to inter-annual availability and residual bias in the satellite record. The pre- and post 2000 have temperature records from two separate satellites and the discrepancy in the trends needs to be resolved[23]

This is challenge we need to face and work on improving the parametrizations. The new era of super high resolution models would resolve the complex interactions of turbulence, transport and clouds and will provide less uncertainty[24]. However, this can't be used to invalidate the entire set of models, the models are performing remarkably well given the complex system that is being modeled. It should be noted the models do cover the range of the observations and it is not outside the envelope of model predictions.

Part of the problem here may be which part of the stratosphere is sampled and the importance of interannual variabilities in the lower part of the stratosphere. [25] have shown that including the stratosphere as defined from 25 to 50km there is high confidence that the cooling signal caused by CO2 increase is detectable and beyond the noise levels of the natural and inter annual variability in the lowest part of the stratosphere. We should put this debate to rest.

Given the large uncertainties in obtaining data over much of the Northern Hemisphere, using a smaller regional analysis to discount the models may be inappropriate. We should that this remains a question we need to resolve developing better datasets with more seasonal and sub-seasonal coverage to test the model on a global scale

This statement from [26] refers to the fitness of global scale models to resolve regional scale features and argues for developing model at higher spatial resolutions. Using downscaling and other techniques additional insights can be gained at regional scales and provide information for a set of 'purposes'. However, we should work on getting to regional and local scales with GCM as quickly as possible.

Looking for trends or estimating trends in extreme events in current and future climate is not necessarily an attribution study. Estimating frequency, duration and intensity of events helps understand the changing range of the hazard (if there is one). An attribution would be to find to what extent a particular event is influenced or affected by increase in CO2. I would consider these two not to be the same. Attributing any single event to changing climate is perilous, agreed.

As noted by [26] there is not yet any strong evidence that LPT is a fact

I am not sure how one can conclude that the temperature extremes have decreased based on figure 6.3.4. If I understand correctly the Tmax-Tmin for each year was tabulated and a mean of this difference averaged over the 100+ years was subtracted from these values to get some thing like a anomaly. This anomaly seems to have moved from +3F to -3F over the course of q00 years and now trending upwards again. This suggests to me that there has been significant changes in the extremes over the years and the most recent trend is towards warmer highs?

The NCA5 is suggesting that the western US is experiencing increase in extreme heat (page 57, para 4); it seems like figure 6.3.5 establishes the fact and not contradict. There was no claim of pervasive (all CONUS) increase in the report

The definition of heat wave as consecutive 6 days seems to be a special case. The standard definition is exceedance of 85 or 90 percentile for 2 or more days. I can't check with NCA5 as it was taken down from the web

Figure 6.3.6 establishes that heatwaves as defined here have increased in the west and have shown increasing trend all over CONUS in the past 50 years. [27] shows the results for the last 60 years and there is little doubt that there is an increase over most of the CONUS, again the NCA5 report is off the web; figure 6.3.7 shows the heat waves are monotonically increasing from the 1960. Including the longer data is only interesting in the dust bowl 1930 camouflage the signal somewhat for the Midwest and central plains. The problem of taking averages over large regions (for example entire CONUS) is that it kills the peak signals and smooths out the emergent climate change indicators. Doing continental averages to look for extremes is really not very useful. Secondly, there is no particular reason to assume that the climate change signal (i.e. the number of heat waves) should showing up 100 years ago, as the CO2 in the atmosphere started to be of significance in the last 50 years.

averaged over all stations in the region, none of these trend parameters is statistically significant'. This is again how one would be looking at statistics of extremes in precipitation. As we know, precipitation is highly heterogeneous and location dependent. As observed there are trends even with the approaches chosen by the authors of this study compared to NCA5 and averaging that over and saying there is no trend seems disingenuous.

same argument as above

again the issue here is that we are talking about events that are happening in a short-time and over a small region. Averaging over time and space and develop statistics is probably not appropriate when we are talking about events such as the recent flooding event in Texas. If you average that event over 30 days, it will seem unremarkable.

As noted in NCA5 and shown in the analysis presented in figure 6.4.4 there is a clear trend of increase in extreme precipitation in 12 of the 27 stations analyzed. Again averaging over the entire region is not the best method for picking extreme precipitation events that are local both in time and space.

However, there is evidence that flash droughts, which last weeks have increased over the Northeast and Midwest [28]

More recent analysis indicate forest loss due to wildfire accelerating over the recent past[29]. In particular there has been an increase in extreme fire radiative power with a 2 fold increase from 2003 to 2023 (period of satellite data availability)[30][31]. However, that these fires are not out-of-sample and there is a fire deficit as shown in figure 6.8.2 should be acknowledged. But this doesn't alleviate the concern that wildfire is leading to lot of socio-economic concerns and needs to be addressed[32]

The question of forest management and its role on wildfire frequency and intensity is interesting and deserves further study.

The global mean sea-level was increasing at a rate of 0.08 inches/yr in 1993 compared 0.18 inches/yr in 2023, almost double the rate[33], which is approximately what is needed to meet the NOAA projections by mid-century and seems plausible.

A possible reason the method used by IPCC (optimal fingerprinting) can be considered to address McKitnick criticism is in [34]

The role of clouds remains the single most uncertainty in climate modeling, I am glad this was acknowledged here.

The substance of this paragraph was addressed in my comments in earlier sections. Some of the claims made here are either exaggerations of the usual practice (RCP8.5 being referred to as BAU) or the comment about not fit for purpose (a comment extracted from a publication that is calling out for cloud resolved models.

The problem with both the FACE studies and the soybean. Maize and wheat studies cited here are that they don't consider the effect of increase in temperature, changes in precipitation, humidity and other environmental factors along with CO2 increases. These compound effects have been shown in wide number of studies [35] [36][37][38][39]. A meta analysis of the compound effects shows that increase in CO2, along with temperature, precipitation changes effects the quality of the cereal and yields[40]. Another recent study evaluated the impacts on C3 and C4 crops and conclude that CO2 enrichment for C3 crops could increase but will be compensated by temperature increase. CO2 fertilization effect was found to be small for C4 [41]. It is important therefore that we consider the compound effects on crop yields and not just focus on CO2 enrichment.

Taylor and Schlenker 2021 also note that 'Climate change will likely have negative impact on agriculture in aggregate, especially in regions exposed to extreme heat. And the CO2-driven yield increases may be offset be effects on food nutrition and quality'. However, the results for US have been a net positive in the recent past but not true in the lower latitudes.

The criticism of NOAA Billion dollar map is likely warranted as it was never completely transparent how the data was generated. However, changing the baseline assumption and refactoring the data using a different set of criteria to make the effects smaller also doesn't make sense. We should continue collecting this data and make the data accessible for researchers and peer review. Figure 10.1 doesn't address these issues, it is another methodology with unknown province of the data.

Climate change can be expected to increase cold weather extremes in regions that have not been exposed to these effect

The same Nobel prize winning model in its most recent study concludes that [42] "We conclude with three results relevant for climate policy. First, both current policies (base run) and the extended Paris Accord fall short of limiting global warming to 2 °C or to the cost–benefit optimal level. Second, the economic stakes in global climate policy are substantial, with estimated net present value of economic benefits around \$120 trillion from the cost–benefit optimal policy. Third, once differences in discounting are considered, the baseline DICE-2023 estimate of the social cost of carbon (\$66/tCO₂ for 2020) aligns closely with other recent estimates". Obviously this is the latest and the current version of the model and these results are quite different from thus discussed on this page. These conclusions should also be included in this discussion to avoid selective reading of the literature.

Similar empirical studies [43] point to "Using an empirical approach that provides a robust lower bound on the persistence of impacts on economic growth, we find that the world economy is committed to an income reduction of 19% within the next 26 years independent of future emission choices (relative to a baseline without climate impacts, likely range of 11–29% accounting for physical climate and empirical uncertainty). These damages already outweigh the mitigation costs required to limit global warming to 2 °C by sixfold over this near-term time frame and thereafter diverge strongly dependent on emission choices. Committed damages arise predominantly through changes in average temperature, but accounting for further climatic components raises estimates by approximately 50% and leads to stronger regional heterogeneity. Committed losses are projected for all regions except those at very high latitudes, at which reductions in temperature variability bring benefits. The largest losses are committed at lower latitudes in regions with lower cumulative historical emissions and lower present-day income". This study uses more of the daily temperature precipitation from 1600 hundred locations world wide instead of global means. There are numerous studies that show the cost, many described in the COP 21 and follow-on meetings

while small in terms of global emissions (just from the US transport sector), over period this will be significant reduction. We need to remember that US is the second highest emitter of CO₂.

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Francesco S.R. Pausata, Marco Gaetani, Gabriele Missouri, Alexis Berg, Danielle Maia de Souza, Rowan F. Sage, Peter B. deMenocal, The Greening of the Sahara: Past Changes and Future Implications, *One Earth*, Volume 2, Issue 3, 2020, Pages 235-250, ISSN 2590-3322, <https://doi.org/10.1016/j.oneear.2020.03.002>.

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[14] Ursula M. Ruiz-Vera, Matthew Siebers, Sharon B. Gray, David W. Drag, David M. Rosenthal, Bruce A. Kimball, Donald R. Ort, Carl J. Bernacchi, Global Warming Can Negate the Expected CO₂ Stimulation in Photosynthesis and Productivity for Soybean Grown in the Midwestern United States, *Plant Physiology*, Volume 162, Issue 1, May 2013, Pages 410–423, <https://doi.org/10.1104/pp.112.211938> [15] Lamba S, Hall M,

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[22] Hausfather, Z., Drake, H. F., Abbott, T., & Schmidt, G. A. (2020). Evaluating the performance of past climate model projections. *Geophysical Research Letters*, 47, e2019GL085378. <https://doi.org/10.1029/2019GL085378>

The Chung et al. study (which did not go beyond 2014) confirms the models' too-high warming rates as well as documenting the shift in tropospheric temperatures of the RSS and UW datasets (which share very similar choice of satellites) relative to UAH and NOAA/STAR (which rely on empirical tests to determine when a satellite drifts too much). Christy et al. 2018 specifically examined the relative jump in RSS and UW datasets around 2000 finding that compared with other independent measures, the RSS and UW retain spurious warming from the aging NOAA-14 satellite. Thus the notion that satellite biases are an issue applies predominantly to RSS and UW. We agree that the timing of major events like ENSOs diminishes the fidelity of models to observations comparisons, but now with 46 years of record in Fig. 5.7, this concern is less valid. Be that as it may, CGW Fig. 5.7 is clear in noting all models overestimate the tropical temperature trend - even more positive than that of RSS and the two Reanalyses. [23] Chung, ES., Kim, SJ., Sohn, BJ. et al. Multi-decadal climate variability and satellite biases have amplified model-observation discrepancies in tropical troposphere warming estimates. *Commun Earth Environ* 5, 342 (2024). <https://doi.org/10.1038/s43247-024-01510-8>

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For each station and each year, the hottest day and coldest night are determined and their difference cc

As correctly suggested by Reviewer 1, there are numerous ways to define a heat wave. CWG chose to

As discussed in the CWG text, the EPA chart is (1) based on nighttime temperatures in the 50 largest l

Extreme event totals are 1-day to 5-days depending on section discussed.

The paper referenced by Reviewer 1 begins with data so recent (1999) that it cannot provide evidence for long-term changes in drought even though it suggests an increase in "flash droughts" over that period. Keep in mind, the DM is a product of subjective interpretation and objective measures - objective measures that have changed considerably during the past 25 years. (One of the CWG authors was an official contributor to the DM for 15 years.) One would wonder what would the 1920's, 30's and early 50's reveal if the DM was operational back then? A more consistent metric is provided in CWG Fig. 6.7.1.

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[29] Tyukavina Alexandra, Potapov Peter, Hansen Matthew C., Pickens Amy H., Stehman Stephen V., Turubanova Svetlana, Parker Diana, Zalles Viviana, Lima André, Kommareddy Indrani, Song Xiao-Peng, Wang Lei, Harris Nancy; Global Trends of Forest Loss Due to Fire From 2001 to 2019, *Frontiers in Remote Sensing*. Volume 3 – 2022, 2022.

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<https://doi.org/10.1038/s43247-024-01761-5>

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<https://doi.org/10.2135/cropsci2003.1548> [39] Lesk,

C., Anderson, W., Rigden, A. et al. Compound heat and moisture extreme impacts on global crop yields under climate change. *Nat Rev Earth Environ* 3, 872–889 (2022).

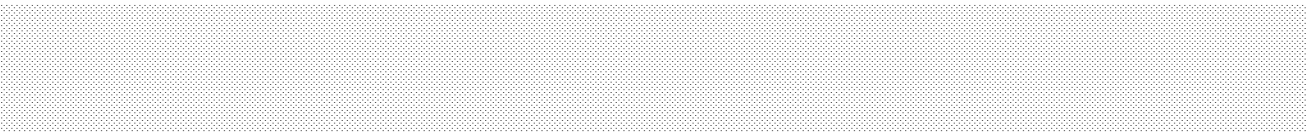
<https://doi.org/10.1038/s43017-022-00368-8>

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te Group Inc., 2024.

omputed. These differences are then geographcially averaged for the CONUS and then an overall ε

o follow one defimtion discussed in NCA4 (pg 191) and use 6 consecutive days with Tmax > 90th pe

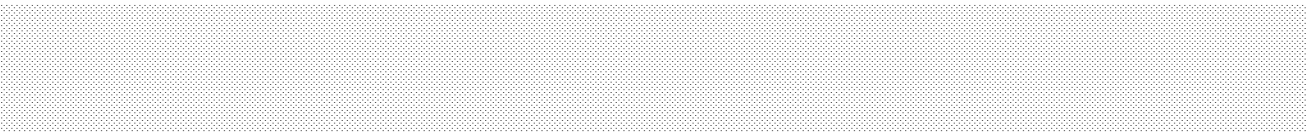
JS cities and (2) begins in 1961 which was the start of the coolest decade in over 100 years, thereby



average is removed to show the results as a type of anomaly. Reviewer 1 is correct, as indicated in

percentile so to allow for consistent comparisons. However, changing the parameters will do little to e

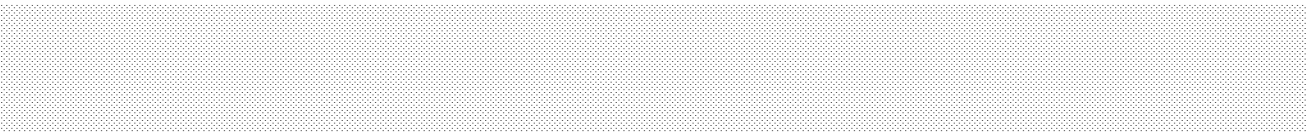
preconditioning the chart to have an upward trend. Urbanization is most clearly seen in nighttime te



the text, Tmin temperatures are almost universally rising more rapidly than Tmax, hence, the difference

alter the fundamental result that the 1920's to early 1950's contain the major heat wave events for the

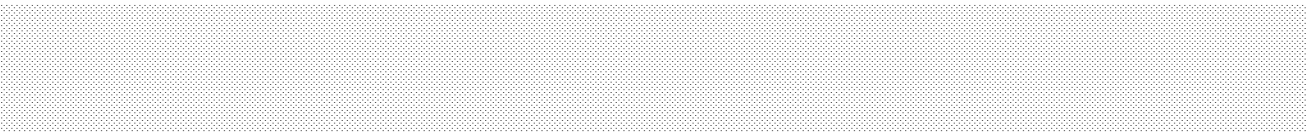
temperature increases so this does not represent a change in the background climate, but more likely



nce (or range) has declined overall. The flattening (or slight rise in the metric) in the past 20 years is

e CONUS.

/ the local climates of cities. Rural areas show less nighttime warming. And avoiding earlier warm p



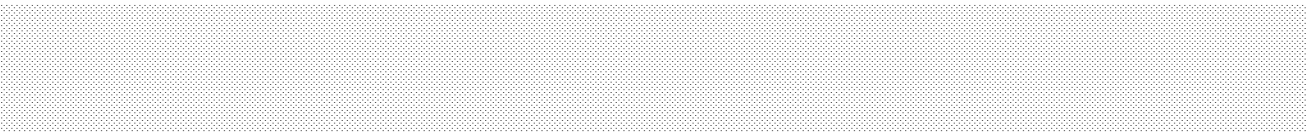
s clearly within the natural range, but does reveal an interesting stair-step pattern with rapid declines

periods does not provide information on the larger scale of natural variability. [27]<https://www.epa.gov>

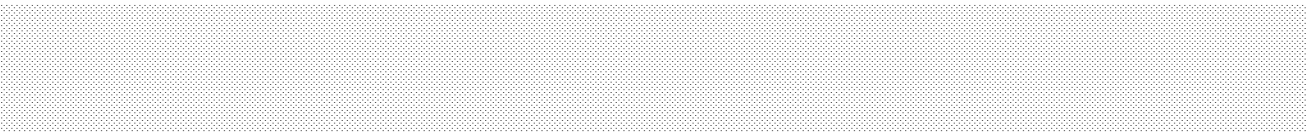


; centered around the 1940's and 1990's and relatively flat periods in between. An explanation is ur

v/climate-indicators/climate-change-indicators-heat-waves



nder investigation, and a leading hypothesis is that there was rapid growth of manufactured surfaces



; around weather stations in the 1940s. Then, in the 1960s-80s many stations were re-located to rel



latively rural airports, which then experienced subsequent growth in manufactured surfaces around



their weather statio

On Jul 19, 2025, at 3:19 PM, Fisher, Travis <travis.fisher@hq.doe.gov> wrote:

Hi Judy, the Excel version is the only version I have, but I have tried to move the comments into a Word doc. I am off to a wedding now, but I should be able to finish the conversion tomorrow. The attached file is my start. Does this format work better? Do you want me to include the citations when I finish tomorrow?

From: Judith Curry <curry.judith@gmail.com>

Sent: Saturday, July 19, 2025 3:46 PM

To: Fisher, Travis <travis.fisher@hq.doe.gov>

Cc: John Christy

<climatemanager60@gmail.com>; roywspencer@hotmail.com; ross.mckitrick@gmail.com; steven.koonin@gmail.com;

Loucks, Joshua <Joshua.Loucks@hq.doe.gov>; Cohen, Seth <seth.cohen@hq.doe.gov>

Subject: Re: [EXTERNAL] Re: Draft DOE report for review

Travis, is there a .doc msword version of the review? I find this version fairly incomprehensible. I can copy text and try to make a msword doc out of this if such a version isn't available. Thanks

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From: John Christy <climatemanager60@gmail.com>

Sent: Saturday, July 19, 2025 11:47 AM

To: Fisher, Travis <travis.fisher@hq.doe.gov>

Cc: roywspencer@hotmail.com; curry.judith@gmail.com; ross.mckitrick@gmail.com; steven.koonin@gmail.com;

Loucks, Joshua <Joshua.Loucks@hq.doe.gov>; Cohen, Seth <seth.cohen@hq.doe.gov>

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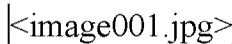
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curry.judith@cfanclimate.com | +1.404.803.2012
<http://www.cfanclimate.net>

<Review 1.docx>

From: Judith Curry <curry.judith@gmail.com>
Sent: Saturday, July 19, 2025 4:24 PM
To: Travis Fisher
Cc: John Christy; roywspencer@hotmail.com; ross.mckitrick@gmail.com;
steven.koonin@gmail.com; Loucks, Joshua; Cohen, Seth
Subject: Re: [EXTERNAL] Re: Draft DOE report for review

Sending this to Travis' gmail acct. The reviewer comments are fairly substantive, at least several are worth addressing in the CWG report.

Mainly writing this email because the report is a bit schizo in terms of whether it is about CO2 or anthro GHG, or climate change. CO2 is in the title. I think we need to reconsider the title of the CWG report, maybe this

Impacts of Carbon Dioxide and other Greenhouse Gas Emissions on the US Climate

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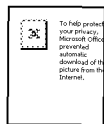
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From: Fisher, Travis [travis.fisher@hq.doe.gov]
Sent: 7/19/2025 8:19:58 PM
To: Judith Curry [curry.judith@gmail.com]
CC: John Christy [climatemanager60@gmail.com]; roywspencer@hotmail.com; ross.mckitrick@gmail.com; steven.koonin@gmail.com; Loucks, Joshua [Joshua.Loucks@hq.doe.gov]; Cohen, Seth [seth.cohen@hq.doe.gov]
Subject: RE: [EXTERNAL] Re: Draft DOE report for review
Attachments: Review 1.docx

Hi Judy, the Excel version is the only version I have, but I have tried to move the comments into a Word doc. I am off to a wedding now, but I should be able to finish the conversion tomorrow. The attached file is my start. Does this format work better? Do you want me to include the citations when I finish tomorrow?

From: Judith Curry <curry.judith@gmail.com>
Sent: Saturday, July 19, 2025 3:46 PM
To: Fisher, Travis <travis.fisher@hq.doe.gov>
Cc: John Christy <climatemanager60@gmail.com>; roywspencer@hotmail.com; ross.mckitrick@gmail.com; steven.koonin@gmail.com; Loucks, Joshua <Joshua.Loucks@hq.doe.gov>; Cohen, Seth <seth.cohen@hq.doe.gov>
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To: Fisher, Travis
Cc: climateman60@gmail.com; roywspencer@hotmail.com; ross.mckitrick@gmail.com; steven.koonin@gmail.com; Loucks, Joshua; Cohen, Seth
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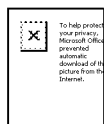
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Comment or Suggested Edit

The greening effect can't be due to increase in CO₂ alone. The fertilization effect needs Nitrogen and phosphorous. There is observational[1] evidence that nitrogen available to plants is decreasing with increasing CO₂ and thus acting to limit fertilization effect. Secondly, the greening of some portions of the planet are likely due to changes in precipitation patterns associated with changing climatic conditions and not entirely attributable to fertilization effect. We will also need to consider that the temperature effect on photosynthesis will also be a limiting mechanism to any continued greening due to fertilization in the future [2]. I recommend acknowledging that the greening is not attributable to CO₂ alone and continued greening in the future with increasing CO₂ is uncertain.

I am glad we acknowledge that CO₂ causes warming, though I am not sure why we are not considering other energy sector related emissions that also cause warming (CFCs/HFCs, methane, aerosol effects). It is not clear what is meant by "CO₂ emissions have tended to overestimate observed trends". This is not correct, the cumulative emissions track the RCP8.5 scenario the closest [3,4]. While there was a decrease in emissions during the Covid-19 period the emissions are now back on track following RCP8.5. This statement should clarify what is meant by the statement in the text.

This paragraph seems to be talking about equilibrium climate sensitivity. The most recent model inter-comparison gives a wider range of climate sensitivities in the range of 1.8 to 5.7 and is wider than estimates of climate sensitivities that have been estimated from paleoclimatic and more recent historical datasets, in the range could be in the range of 2.3 to 4.5 K[5]. The higher sensitivity in the most recent model assessments are an area of active investigation by modelers, the feasibility of a higher range needs to be confirmed with additional observational and process scale modeling [6]. The range for climate sensitivities, 1.8-2.7, should be corrected to the most recent findings, 2.3-4.5. We should also recognize that the (a)earth is a complex system of systems (b)we can't do an experiment to find out what is correct or reduced the uncertainty. As we get better at extracting temperature records and CO₂ concentrations from paleo data, there will be better reconstructions and possibly narrower range along with improvements in modeling that resolve many physical, biological and chemical processes as we get to higher and cloud resolving spatial resolutions.

This is again not true for the majority of the models in the AR6. Figure 7.19 in the IPCC AR6 report shows that majority of the models exhibit a range within the observational range. The models running hot in the most recent decades are the ones with climate sensitivities greater than 5K, which are 3 out of a total of 40 and it should be noted that about the same number of models also are running cold' compared to observed[7]

There is very little dispute that these are challenging issues for climate science. Many of the issues identified here related to compound effects (subsidence and sea-level rise; wildfire and forest management) that requires further scientific investigation. Identifying further research avenues/focus areas will be helpful to firm up some of the challenges faced in using the climate projections as discussed in the paragraph 9.

The focus on uncertainty is relevant and should be emphasized in future research. However, as a reasonable policy pathways, making decisions in the face of these uncertainties is critical. Most of the climate uncertainties that we have confidence at this time can be considered Level 2 and Level 3 uncertainties, approaches such as scenario analysis (and others) are suggested and followed for making hazard and risk estimates for future conditions. For deep uncertainty hazards (for example tornadoes etc.) that we don't have enough data or capability to model, developing methods for assessing the uncertainty and risk should be a focus of future research.

The reason CO₂ was identified as a pollutant is the health consequences of increased temperature, flooding and other climate impacts and not because of any direct affect on health due to exposure to atmospheric CO₂[8]. The summary should note that CO₂ fertilization effects are limited by the availability of other critical plant nutrients (Nitrogen, Phosphorous). The fertilization effect is also constrained by higher temperature effecting photosynthesis[9]

The attribution of greening to primarily CO₂ fertilization is questionable as per recent research. Specifically, in the Northern high latitudes (where the greening is most prominent), increases in temperatures due to climate change has been shown to provide the best explanation[10]. In the sub-Saharan region reforestation efforts and changing precipitation patterns lead to some of the observed greening (the great green wall) [11]. The attribution to CO₂ fertilization should be qualified by noting the other present and emerging constraints.

This summarization ignores the compound effects of temperature, moisture and CO₂ fertilization in assessing the impacts of CO₂ increase on vegetation and crop yields. Many studies have shown that [12]. Making note of these compensating factors is required for a balanced view on CO₂ fertilization effects on plants. Chen et al. (2024)[13] conclude that "In the attribution analysis of LAI trend and growth rate trend, there were some differences between multiple linear regression model and partial correlation analysis at high latitudes in the northern hemisphere. Partial correlation analysis showed that LAI trend and growth rate trend in this region were mainly affected by temperature and radiation, while multiple linear regression suggested that CO₂ was the dominant driver. The results of the partial correlation analysis seem more reasonable because some previous studies have shown that vegetation change in the high latitudes of the northern Hemisphere is mainly positively affected by climate warming. Multiple linear regression model performed relatively poorly in this region and might not fully identify the contribution of individual drivers. In addition, our model does not include the contribution of land management, which has been highlighted in some previous studies. Of course, the contribution of land management to LAI trend and growth rate trend may be implied in other drivers, such as the positive contribution of CO₂ to LAI trend in PP and PN areas".

This again suffers from not acknowledging the effects of compound and often compensating phenomena that is occurring with the on-going climate change. For example [14] note that much of the Midwest any benefit from CO₂ fertilization will be negated by temperature increases. [15] note that "Our results show that long-term physiological acclimation dampens the initial stimulation of plant net carbon assimilation to elevated [CO₂], and of plant water use to warming."

The fallacy of these arguments in terms of PH changes and evolution is that the changes described in this paragraph occurred over millennia and the evolutionary process had time to adapt; here with climate change we are talking about changes in our lifetime, the speed of change is the issue. This will lead to collapse of some ecosystem and by the time adaptation takes place it will be millions of years and in a different climate - not the one we have now and that enabled the rise of humans.

A simple calculation will show us how misleading this figure is. It shows that over 600 Million years CO₂ changed by around 6000ppm. That is a rate of change of 0.00001/yr; CO₂ changed from 275 to 430 in the past 175 years, that is rate of change of 0.88ppm/yr. A change in the rate of over 10⁵ in magnitude - there in lies the problem. We are seeing a rapid increase in CO₂ that has never been witnessed and the ecosystem and huma society (which is at best 10K years old), may not be able to adapt to this rapid change.

The misuse of RCP8.5 as business as usual is acknowledged. However, this was never intended to be a no-policy or business as usual scenario but as a high-end baseline scenario. When dealing with interaction of physical systems with socio-economic projections (which tend to be highly uncertain and policy dependent), the development of this high baseline scenarios is intended to explore the uncertainty ranges that represent a high-end scenario[16,17]. As any engineer would acknowledge, this is a prudent approach when dealing with L3 and L4 type deep uncertainties and provide valid envelopes for assessing uncertainties and risks from high impact events/hazards. The rest of the statements here are uncertainties acknowledged by the climate scientists and included in developing projections and discussing the results[4]. Does the IPCC downplay the role of sun in climate change? The IPCC includes sun variability in all its assessments from the beginning and has been acknowledged as a potential but insignificant contributor.

Please see above. The business-as-usual may be a misnomer but this is an 95% case that is typically included in any type of prudent uncertainty analysis, in particular given the difficulty of predicting the evolution of socio-economic and political conditions over the next 100 years. It should be noted the difference between RCP8.5 and RCP4.5 for mid-century conditions that is of particular focus for adaptation studies in not significant and most of the divergence in these two scenarios occurs later in the century.

That the dynamic vegetation models need more development is acknowledged and is a defining challenge for Earth System Modeling for the next decade.

As noted, Parker[18,19,20] has investigated the Urban effects on temperature records. The finding establish that by comparing warm and wind conditions world wide that the impact is negligible. However, as noted by authors, this literature hasn't progressed much over the last decade and much more attention needs to be paid to this question by employing newer models, datasets and analytical techniques available to us at present.

We can all agree that there is a desperate need for developing higher-resolution climate models that can get to cloud resolving scale so that we can represent the cloud feedbacks correctly in the model and avoid uncertainties from parameterization and scale dependency of the parameters. This doesn't make these models useless. The models provide directions for further improvements and necessary changes to reduce the uncertainty bands over the ECS.

The databased approaches have mostly been robust with changes at the high end around 3-4C and at the low end around 1.8 to 2.5C as noted in the chapter. It will be challenging to make this range shorter given the data requirements and uncertainties in data over paleo/haloocene periods. It seems reasonable to estimate that we may have ECS in the range of 3 to 4K (higher than 3.5K being less likely [21]) at the higher end and this should not prevent us from planning and thinking on ways to prevent this possible scenario as it could have major consequences for humans across the planet.

The models range over a factor of three in ECS comparing the most sensitive to the least sensitive models. However vast majority of the models are in 3 to 3.5K sensitivity range and it is probably not correct to assign all models the same amount of importance, given the fact that some of institutes participating in the exercise have different levels of capacity to develop and test models.

While this analysis for the CMIP6 model set is accurate and focuses on a dataset that has shown higher ECS than previous iterations, it should be noted the models have exhibited considerable skill in predicting the subsequent GMST warming[22]. The criticism of the CMIP6 based high ECS models may be premature and probably will have to wait additional time before passing judgement. As noted in [22] these models have shown considerable skill when evaluated on their projections over the past 30-40 years after the projections were published.

A recent study attributes the bias to inter-annual availability and residual bias in the satellite record. The pre- and post 2000 have temperature records from two separate satellites and the discrepancy in the trends needs to be resolved[23]

This is challenge we need to face and work on improving the parametrizations. The new era of super high resolution models would resolve the complex interactions of turbulence, transport and clouds and will provide less uncertainty[24]. However, this can't be used to invalidate the entire set of models, the models are performing remarkably well given the complex system that is being modeled. It should be noted the models do cover the range of the observations and it is not outside the envelope of model predictions.

Part of the problem here may be which part of the stratosphere is sampled and the importance of interannual variabilities in the lower part of the stratosphere. [25] have shown that including the stratosphere as defined from 25 to 50km there is high confidence that the cooling signal caused by CO2 increase is detectable and beyond the noise levels of the natural and inter annual variability in the lowest part of the stratosphere. We should put this debate to rest.

Given the large uncertainties in obtaining data over much of the Northern Hemisphere, using a smaller regional analysis to discount the models may be inappropriate. We should that this remains a question we need to resolve developing better datasets with more seasonal and sub-seasonal coverage to test the model on a global scale

This statement from [26] refers to the fitness of global scale models to resolve regional scale features and argues for developing model at higher spatial resolutions. Using downscaling and other techniques additional insights can be gained at regional scales and provide information for a set of 'purposes'. However, we should work on getting to regional and local scales with GCM as quickly as possible.

Looking for trends or estimating trends in extreme events in current and future climate is not necessarily an attribution study. Estimating frequency, duration and intensity of events helps understand the changing range of the hazard (if there is one). An attribution would be to find to what extent a particular event is influenced or affected by increase in CO2. I would consider these two not to be the same.

Attributing any single event to changing climate is perilous, agreed.

As noted by [26] there is not yet any strong evidence that LPT is a fact

I am not sure how one can conclude that the temperature extremes have decreased based on figure 6.3.4. If I understand correctly the Tmax-Tmin for each year was tabulated and a mean of this difference averaged over the 100+ years was subtracted from these values to get some thing like a anomaly. This anomaly seems to have moved from +3F to -3F over the course of q00 years and now trending upwards again. This suggests to me that there has been significant changes in the extremes over the years and the most recent trend is towards warmer highs?

The NCA5 is suggesting that the western US is experiencing increase in extreme heat (page 57, para 4); it seems like figure 6.3.5 establishes the fact and not contradict. There was no claim of pervasive (all CONUS) increase in the report

The definition of heat wave as consecutive 6 days seems to be a special case. The standard definition is exceedance of 85 or 90 percentile for 2 or more days. I can't check with NCA5 as it was taken down from the web

Figure 6.3.6 establishes that heatwaves as defined here have increased in the west and have shown increasing trend all over CONUS in the past 50 years. [27] shows the results for the last 60 years and there is little doubt that there is an increase over most of the CONUS, again the NCA5 report is off the web; figure 6.3.7 shows the heat waves are monotonically increasing from the 1960. Including the longer data is only interesting in the dust bowl 1930 camouflage the signal somewhat for the Midwest and central plains. The problem of taking averages over large regions (for example entire CONUS) is that it kills the peak signals and smooths out the emergent climate change indicators. Doing continental averages to look for extremes is really not very useful. Secondly, there is no particular reason to assume that the climate change signal (i.e. the number of heat waves) should showing up 100 years ago, as the CO2 in the atmosphere started to be of significance in the last 50 years.

averaged over all stations in the region, none of these trend parameters is statistically significant'. This is again how one would be looking at statistics of extremes in precipitation. As we know, precipitation is highly heterogenous and location dependent. As observed there are trends even with the approaches chosen by the authors of this study compared to NCA5 and averaging that over and saying there is no trend seems disingenuous.

same argument as above

again the issue here is that we are talking about events that are happening in a short-time and over a small region. Averaging over time and space and develop statistics is probably not appropriate when we are talking about events such as the recent flooding event in Texas. If you average that event over 30 days, it will seem unremarkable.

As noted in NCA5 and shown in the analysis presented in figure 6.4.4 there is a clear trend of increase in extreme precipitation in 12 of the 27 stations analyzed. Again averaging over the entire region is not the best method for picking extreme precipitation events that are local both in time and space.

However, there is evidence that flash droughts, which last weeks have increased over the Northeast and Midwest [28]

More recent analysis indicate forest loss due to wildfire accelerating over the recent past[29]. In particular there has been an increase in extreme fire radiative power with a 2 fold increase from 2003 to 2023 (period of satellite data availability)[30][31]. However, that these fires are not out-of-sample and there is a fire deficit as shown in figure 6.8.2 should be acknowledged. But this doesn't alleviate the concern that wildfire is leading to lot of socio-economic concerns and needs to be addressed[32]

The question of forest management and its role on wildfire frequency and intensity is interesting and deserves further study.

The global mean sea-level was increasing at a rate of 0.08 inches/yr in 1993 compared 0.18 inches/yr in 2023, almost double the rate[33], which is approximately what is needed to meet the NOAA projections by mid-century and seems plausible.

A possible reason the method used by IPCC (optimal fingerprinting) can be considered to address McKitnick criticism is in [34]

The role of clouds remains the single most uncertainty in climate modeling, I am glad this was acknowledged here.

The substance of this paragraph was addressed in my comments in earlier sections. Some of the claims made here are either exaggerations of the usual practice (RCP8.5 being referred to as BAU) or the comment about not fit for purpose (a comment extracted from a publication that is calling out for cloud resolved models.

The problem with both the FACE studies and the soybean, Maize and wheat studies cited here are that they don't consider the effect of increase in temperature, changes in precipitation, humidity and other environmental factors along with CO2 increases. These compound effects have been shown in wide number of studies [35][36][37][38][39]. A meta analysis of the compound effects shows that increase in CO2, along with temperature, precipitation changes effects the quality of the cereal and yields[40]. Another recent study evaluated the impacts on C3 and C4 crops and conclude that CO2 enrichment for C3 crops could increase but will be compensated by temperature increase. CO2 fertilization effect was found to be small for C4 [41]. It is important therefore that we consider the compound effects on crop yields and not just focus on CO2 enrichment.

Taylor and Schlenker 2021 also note that 'Climate change will likely have negative impact on agriculture in aggregate, especially in regions exposed to extreme heat. And the CO2-driven yield increases may be offset by effects on food nutrition and quality'. However, the results for US have been a net positive in the recent past but not true in the lower latitudes.

The criticism of NOAA Billion dollar map is likely warranted as it was never completely transparent how the data was generated. However, changing the baseline assumption and refactoring the data using a different set of criteria to make the effects smaller also doesn't make sense. We should continue collecting this data and make the data accessible for researchers and peer review. Figure 10.1 doesn't address these issues, it is another methodology with unknown province of the data.

Climate change can be expected to increase cold weather extremes in regions that have not been exposed to these effect

The same Nobel prize winning model in its most recent study concludes that [42] "We conclude with three results relevant for climate policy. First, both current policies (base run) and the extended Paris Accord fall short of limiting global warming to 2 °C or to the cost–benefit optimal level. Second, the economic stakes in global climate policy are substantial, with estimated net present value of economic benefits around \$120 trillion from the cost–benefit optimal policy. Third, once differences in discounting are considered, the baseline DICE-2023 estimate of the social cost of carbon (\$66/tCO₂ for 2020) aligns closely with other recent estimates". Obviously this is the latest and the current version of the model and these results are quite different from thus discussed on this page. These conclusions should also be included in this discussion to avoid selective reading of the literature.

Similar empirical studies [43] point to "Using an empirical approach that provides a robust lower bound on the persistence of impacts on economic growth, we find that the world economy is committed to an income reduction of 19% within the next 26 years independent of future emission choices (relative to a baseline without climate impacts, likely range of 11–29% accounting for physical climate and empirical uncertainty). These damages already outweigh the mitigation costs required to limit global warming to 2 °C by sixfold over this near-term time frame and thereafter diverge strongly dependent on emission choices. Committed damages arise predominantly through changes in average temperature, but accounting for further climatic components raises estimates by approximately 50% and leads to stronger regional heterogeneity. Committed losses are projected for all regions except those at very high latitudes, at which reductions in temperature variability bring benefits. The largest losses are committed at lower latitudes in regions with lower cumulative historical emissions and lower present-day income". This study uses more of the daily temperature precipitation from 1600 hundred locations world wide instead of global means. There are numerous studies that show the cost, many described in the COP 21 and follow-on meetings

while small in terms of global emissions (just from the US transport sector), over period this will be significant reduction. We need to remember that US is the second highest emitter of CO₂.

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tte Group Inc., 2024.

From: Ross McKittrick <ross.mckitrick@gmail.com>
Sent: Sunday, July 13, 2025 4:59 PM
To: Judith Curry
Cc: Steven Koonin; Roy W. Spencer; John Christy; Travis Fisher; Josh Loucks; Cohen, Seth
Subject: Re: July 10 edition

I propose we add a few sentences in the CC&Agric chapter on the nutrient density question. There are a couple of recent survey articles that argue nutrient density has declined but it's not necessarily due to CO₂; a lot of things have changed in agric methods since the 50s. Also not all plant types become less nutrient dense due to extra CO₂ so there is likely scope for adaptive breeding and varietal selection. But mostly it's an area that hasn't been researched--too many current unknowns.
I'll write something brief on the next iteration.

On Sun, Jul 13, 2025 at 1:50 PM Ross McKittrick <ross.mckitrick@gmail.com> wrote:
Hi everyone, I'm gradually getting caught up after relocating to Chicago and having a minor tech catastrophe when my phone died taking with it all the 2FA sign in options for email and dropbox.
I'll go through the emails now.

On Sun, Jul 13, 2025 at 11:43 AM Judith Curry <curry.judith@gmail.com> wrote:
My edits to SK's version (including added ref for ECS tuning)

On Sat, Jul 12, 2025 at 7:05 AM Steven Koonin <steven.koonin@gmail.com> wrote:

I've done another close read through it all. Changes indicated in the attached. Mostly typographical, but a few consequential and a very few questions.

SEK

From: Ross McKittrick <ross.mckitrick@gmail.com>
Sent: Thursday, July 10, 2025 10:54 PM
To: Judith Curry <curry.judith@gmail.com>; Roy W. Spencer <roywspencer@hotmail.com>; John Christy <climateman60@gmail.com>; Steven Koonin <steven.koonin@gmail.com>; Travis Fisher <travis.scott.fisher@gmail.com>; Josh Loucks <loucksj14@gmail.com>; Cohen, Seth <seth.cohen@hq.doe.gov>
Subject: July 10 edition

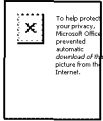
- errata fixed

- Judy's edits accepted except the deletion of the 1st paragraph on p. 37 (extended IPCC quote) since deleting it wrecks the pagination and I think the extended quote is helpful.

- The comment about policy in the exc summary is retained, and I think the economics chapter implicitly make the point

With any luck this is the final version, until we change it again.

--



Judith Curry, President
CFAN - Climate Forecast Applications Network
Reno, NV USA
curry.judith@cfanclimate.com | +1.404.803.2012
<http://www.cfanclimate.net>

From: Ross McKittrick <ross.mckitrick@gmail.com>
Sent: Sunday, July 13, 2025 1:51 PM
To: Judith Curry
Cc: Steven Koonin; Roy W. Spencer; John Christy; Travis Fisher; Josh Loucks; Cohen, Seth
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Reno, NV USA
curry.judith@cfanclimate.com | +1.404.803.2012
<http://www.cfanclimate.net>

From: Judith Curry [curry.judith@gmail.com]
Sent: 7/13/2025 3:42:44 PM
To: Steven Koonin [steven.koonin@gmail.com]
CC: Ross McKittrick [ross.mckittrick@gmail.com]; Roy W. Spencer [roywspencer@hotmail.com]; John Christy [climateman60@gmail.com]; Travis Fisher [travis.scott.fisher@gmail.com]; Josh Loucks [loucksj14@gmail.com]; Cohen, Seth [seth.cohen@hq.doe.gov]
Subject: Re: July 10 edition
Attachments: DoE.Report.ERRATA.FIXED.July07 Curry SK CURRY.docx

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Subject: July 10 edition

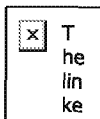
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curry.judith@cfanclimate.com | +1.404.803.2012
<http://www.cfanclimate.net>

From: John Christy <climateman60@gmail.com>
Sent: Saturday, July 12, 2025 3:11 PM
To: Steve Koonin
Cc: Ross McKittrick; Judith Curry; Roy W. Spencer; Travis Fisher; Josh Loucks; Cohen, Seth
Subject: Re: July 10 edition

To whomever is keeping up with the CWG corrections (Ross?)

I've just read through this version: DoE.Report.ERRATA.FIXED.July07 Curry SK

Errata (besides a few places with extraneous spaces)

Pg 54. Now "...of 1,211 CONU.S. stations designated...". Should be "... of 1,211 CONUS stations designated..."

Pg 96 top. Now "U.S. history occurred prior to the first half of the 20th century...". Should be

"... U.S. history occurred in the first half of the 20th century..."

Several places: "tonne" should be placed in glossary as "metric ton" or changed to "metric ton" in the text.

Frankly, I was amazed that between 11 April and 27 May (47 days) this document was created. My amazement recognizes the fact I contributed by far the fewest number of the 53,000 words. I did a lot of dataset building and number crunching, but that's just bookkeeping and arithmetic. Well done.

John C.

John Christy
Director, Earth System Science Center
Professor, Atmos and Earth Science
Alabama State Climatologist
The University of Alabama in Huntsville
climateman60@gmail.com

On Jul 12, 2025, at 9:05 AM, Steven Koonin <steven.koonin@gmail.com> wrote:

I've done another close read through it all. Changes indicated in the attached. Mostly typographical, but a few consequential and a very few questions.

SEK

From: Ross McKittrick <ross.mckittrick@gmail.com>

Sent: Thursday, July 10, 2025 10:54 PM

To: Judith Curry <curry.judith@gmail.com>; Roy W. Spencer <roywspencer@hotmail.com>; John Christy <climateman60@gmail.com>; Steven Koonin <steven.koonin@gmail.com>; Travis Fisher <travis.scott.fisher@gmail.com>; Josh Loucks <loucksj14@gmail.com>; Cohen, Seth <seth.cohen@hq.doe.gov>

Subject: July 10 edition

- errata fixed
 - Judy's edits accepted except the deletion of the 1st paragraph on p. 37 (extended IPCC quote) since deleting it wrecks the pagination and I think the extended quote is helpful.
 - The comment about policy in the exc summary is retained, and I think the economics chapter implicitly make the point
- With any luck this is the final version, until we change it again.

<DoE.Report.ERRATA.FIXED.July07 Curry SK.docx>

From: Steven Koonin [steven.koonin@gmail.com]
Sent: 7/12/2025 2:05:03 PM
To: 'Ross McKittrick' [ross.mckittrick@gmail.com]; 'Judith Curry' [curry.judith@gmail.com]; 'Roy W. Spencer' [roywspencer@hotmail.com]; 'John Christy' [climateman60@gmail.com]; 'Travis Fisher' [travis.scott.fisher@gmail.com]; 'Josh Loucks' [loucksj14@gmail.com]; 'Cohen, Seth' [seth.cohen@hq.doe.gov]
Subject: RE: July 10 edition
Attachments: DoE.Report.ERRATA.FIXED.July07 Curry SK.docx

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- With any luck this is the final version, until we change it again.

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Impacts of Carbon Dioxide Emissions on the U.S. Climate

Climate Working Group
United States Department of Energy
May 27, 2025

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Impacts of Carbon Dioxide Emissions on the U.S. Climate

Report to U.S. Energy Secretary Christopher Wright

May 27, 2025

Climate Working Group:

John Christy, Ph.D.

Judith Curry, Ph.D.

Steven Koonin, Ph.D.

Ross McKittrick, Ph.D.

Roy Spencer, Ph.D.

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Climate Working Group (2025) Impacts of Carbon Dioxide Emissions on the U.S. Climate. Washington DC: Department of Energy, May 27, 2025.

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Table of Contents

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SECRETARY'S FOREWORD

Energy, Integrity, and the Power of Human Potential

Over my lifetime, I've had the privilege of working as an energy entrepreneur across a range of fields—nuclear, geothermal, natural gas, and more—and I now serve as Secretary of Energy under President Donald Trump. But above all, I'm a physical scientist who sees modern energy as nothing short of miraculous. It powers every aspect of modern life, drives every industry, and has made America an energy powerhouse with the ability to fuel global progress.

The rise of human flourishing over the past two centuries is a story worth celebrating. Yet we are told—relentlessly—that the very energy systems that enabled this progress now pose an existential threat. Hydrocarbon-based fuels, the argument goes, must be rapidly abandoned or else we risk planetary ruin.

That view demands scrutiny. That's why I commissioned this report: to encourage a more thoughtful and science-based conversation about climate change and energy. With my technical background, I've reviewed reports from the Intergovernmental Panel on Climate Change, the U.S. government's assessments, and the academic literature. I've also engaged with many climate scientists, including the authors of this report.

What I've found is that media coverage often distorts the science. Many people—even well-meaning ones—walk away with a view of climate change that is exaggerated or incomplete. To provide clarity, I asked a diverse team of independent experts to summarize the current state of climate science, with a focus on how it relates to the United States.

I didn't select these authors because we always agree—far from it. In fact, they may not always agree with each other. But I chose them for their rigor, honesty, and willingness to elevate the debate. I exerted no control over their conclusions. What you'll read are their words, drawn from the best available data and scientific assessments.

I've reviewed the report carefully and challenged its findings. I believe it faithfully represents the state of climate science today. Still, many readers may be surprised by its conclusions—which differ in important ways from the mainstream narrative. That's a sign of how far the public conversation has drifted from the science itself.

To correct course, we need open, respectful, and informed debate. That's why I'm inviting public comment on this report. Honest scrutiny and scientific transparency should be at the heart of our policymaking.

Climate change is real, and it deserves attention. But it is not the greatest threat facing humanity. That distinction belongs to global energy poverty. As someone who values data, I know that improving the human condition depends on expanding access to reliable, affordable energy. Climate change is a challenge—not a catastrophe. But misguided policies based on fear rather than facts could truly endanger human well-being.

We stand at the threshold of a new era of energy leadership. If we empower innovation rather than restrain it, America can lead the world in providing cleaner, more abundant energy—lifting billions out of poverty, strengthening our economy, and improving our environment along the way.

EXECUTIVE SUMMARY

This report reviews scientific certainties and uncertainties in how anthropogenic carbon dioxide (CO₂) emissions have affected, or will affect, the Nation's climate, extreme weather events, and selected metrics of societal well-being. Those emissions are increasing the concentration of CO₂ in the atmosphere through a complex and variable carbon cycle, where some portion of the additional CO₂ persists in the atmosphere for centuries.

Elevated concentrations of CO₂ directly enhance plant growth, globally “greening” the planet and increasing agricultural productivity. They also make the oceans less alkaline (lower the pH) by an amount within the range of natural variability. That is possibly detrimental to coral reefs, although the recent rebound of the Great Barrier Reef suggests otherwise.

Carbon dioxide also acts as a greenhouse gas, exerting a warming influence on climate and weather. Scenarios of future CO₂ emissions have tended to overestimate observed levels.

The world's several dozen detailed climate models offer little guidance on how the climate responds to elevated CO₂, with the average surface warming under a doubling of the CO₂ concentration ranging from 1.8°C to 5.7°C, a larger range than simpler, data driven estimates, which suggest a response in the range 1.8°C to 2.7°C.

Detailed climate models generally run “hot” in their description of the climate of the past few decades - too much warming at the surface and too much amplification of warming in the lower- and mid-troposphere. They also produce too much stratospheric cooling, too much snow loss, and too much warming in the US Corn Belt. The combination of overly sensitive models and extreme scenarios for future emissions has exaggerated projections of future warming.

Most extreme weather events do not show long-term trends. Claims of increased frequency or intensity of hurricanes, tornadoes, floods, and droughts are not supported by historical data. Additionally, forest management practices are often overlooked in assessing wildfire activity. Global sea level has risen approximately 8 inches since 1900, but there are significant regional variations in tide gauge data driven primarily by local land subsidence; U.S. tide gauge measurements in aggregate show no obvious acceleration in sea level rise beyond the historical average rate.

The attribution of particular climate changes or extreme weather events to human CO₂ emissions is challenged by natural climate variability, data limitations, and inherent model deficiencies. Moreover, solar activity's contribution to the warming climate late 20th century warming might be underestimated.

Both models and experience suggest that CO₂-induced warming might be less damaging economically than commonly believed, and excessively aggressive mitigation policies could prove more detrimental than beneficial. Social Cost of Carbon estimates, which attempt to quantify the economic damage of CO₂ emissions, are highly sensitive to their underlying assumptions and so provide limited independent information.

The report supports a more nuanced and evidence-based approach for informing climate policy. The risks and benefits of a climate changing under both natural and human influences must be weighed against the costs, efficacy, and collateral impacts of any “climate action”, considering the nation's need for reliable and affordable energy with minimal local pollution. **THIS IS POLICY AND WE DON'T REALLY DISCUSS THIS. AS DISCUSSED IN EMAILS, WE SHOULD KEEP THIS** Beyond continuing precise, un-interrupted observations of the global climate system, it will be important to make realistic assumptions about future emissions, re-evaluate climate models to address biases and uncertainties, and clearly acknowledge the limitations of extreme event attribution studies. An approach that acknowledges both the

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potential risks and benefits of CO₂, rather than relying on flawed models and extreme scenarios, is essential for informed and effective decision-making.

PREFACE

This document originated in late March 2025 when Secretary Wright assembled an independent group to write a report on issues in climate science relevant for energy policymaking, with particular focus on the question of whether carbon dioxide emissions endanger the U.S. public. We agreed to undertake the work on the condition that there would be no editorial oversight by the Secretary, the Department of Energy, or any other government personnel. This condition has been honored throughout the process and the writing team has worked with full independence.

The group began working in early April with a deadline of May 28. The short timeline and the technical nature of the material meant that we could not comprehensively review all topics. While the report is intended to be accessible to non-experts, we have omitted some introductory or explanatory material that can easily be accessed elsewhere. Nor have we attempted to survey entire literatures related to the topics covered. We have focused as much as possible on literature published since 2020 and referenced previous IPCC and NCA assessment reports. We have also used data through 2024 where possible.

The writing team is grateful to Secretary Wright for the opportunity to prepare this report and for his support of independent scientific assessment and open scientific debate.

John Christy, Ph.D.

Judith Curry, Ph.D.

Steven Koonin, Ph.D.

Ross McKittrick, Ph.D.

Roy Spencer, Ph.D.

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**PART I: DIRECT HUMAN INFLUENCE ON ECOSYSTEMS AND THE
CLIMATE**

1 CARBON DIOXIDE AS A POLLUTANT

Chapter summary:

Carbon dioxide (CO₂) differs in many ways from the so-called Criteria Air Pollutants. It does not affect local air quality and has no human toxicological implications at ambient levels. It is an issue of concern because of its potential effects on the global climate, a complex issue that occupies much of this report.

The Clean Air Act of 1970 defined six so-called Criteria Air Contaminants subject to regulation (EPA): particulate matter, ground-level ozone, sulfur dioxide, nitrogen dioxide, lead, and carbon monoxide. In 2007, the Supreme Court ruled that greenhouse gases (CO₂ among them) were also “pollutants” subject to regulation under Clean Air Act (*Mass. v. EPA*, 2007). While the definition of “pollutant” is ultimately a legal ~~enematter~~ ^{enmatter}, there are important scientific distinctions between CO₂ and the Criteria Air Contaminants. The latter are subject to regulatory control because they cause local problems depending on concentrations that include nuisances (odor, visibility), damage to plants, and, at high enough exposure levels, toxicological effects in humans. In contrast, CO₂ is odorless, does not affect visibility and has no toxicological effects at ambient levels. It is a naturally occurring part of the atmosphere and a key component of human and plant respiration. CO₂ is essential for plant photosynthesis and higher levels are beneficial for vegetation. In these aspects, CO₂ is similar to water vapor.

Ambient outdoor air today contains about 430 parts per million (ppm) CO₂, increasing at about 2 ppm per year. The U.S. Occupational Safety and Health Administration issues guidelines for indoor workplaces in which elevated CO₂ might be encountered, such as where dry ice is used. The Permissible Exposure Limit is 5,000 ppm over 8 hours (OSHA, 2024). Allen *et al.* (2015) reported evidence of diminished performance on some cognitive tasks among workers in office cubicles when exposed to CO₂ levels above 1,000-1,500 ppm. These levels are far larger than any plausible ambient outdoor value through the end of the 22nd century.

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The growing amount of CO₂ in the atmosphere directly influences the earth system by promoting plant growth (global greening), thereby enhancing agricultural yields, and by neutralizing ocean alkalinity. But the primary concern about CO₂ is its role as a greenhouse gas (GHG) that alters the earth's energy balance. How the climate will respond to that influence is a complex question that will occupy much of this report.

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2 DIRECT IMPACTS OF CO₂ ON THE ENVIRONMENT

Chapter summary:

CO₂ enhances photosynthesis and improves plant water use efficiency, thereby promoting plant growth. Global greening due to increased CO₂ levels in the atmosphere is well-established on all continents.

CO₂ absorption in sea water makes the oceans less alkaline. The recent decline in pH is within the range of natural variability on millennial time scales. Most ocean life evolved when the oceans were mildly acidic. Decreasing pH might adversely affect corals, although the Australian Great Barrier Reef has shown considerable growth in recent years.

2.1 CO₂ and global greening

The growing CO₂ concentration in the atmosphere has the important positive effect of promoting plant growth by enhancing photosynthesis and improving water use efficiency. That is evident in the “global greening” phenomenon discussed below, as well as in the improving agricultural yields discussed in Chapter 10.

2.1.1 Measurement of global greening

“Greening” refers to an increase in the fraction of the Earth’s surface covered by plants. It can be quantified by the “Leaf Area Index” (LAI) measured by satellite. Many studies over the past decade have confirmed a global greening pattern (increase in LAI) attributable to rising CO₂ levels. Zhu *et al.* (2016) was one of the first studies to report that global greening was detectable using satellite sensors. From 1982 to 2011 they detected greening over 25-50 percent of the Earth versus “browning” over only 4four percent and attributed 70 percent of the greening to rising CO₂ levels (see Figure 2.1).

Zheng (2017) confirmed the pattern, noting that greening over thirty years had added 8 percent to global leaf area and that greening was mitigating warming. Greening has been observed globally but Chen *et al.* (2019) noted that China and India were exploiting it through land management changes. Thus, while China accounts for only 6.6 percent of global vegetated area it accounts for 25 percent of global net increase in LAI. Piao *et al.* (2020) noted that greening was even observable in the Arctic.

While plant models predict increased photosynthesis in response to rising CO₂, Haverd *et al.* (2020) reported a CO₂ fertilization rate nearly double model predictions. That is, CO₂ fertilization had driven an increase in observed global photosynthesis by 30 percent since 1900, versus 17 percent predicted by plant models. This indicates that global models of the socioeconomic impacts of rising CO₂ have likely understated the benefits to crops and agriculture. The connection between CO₂ fertilization and agriculture will be discussed in Chapter 9.

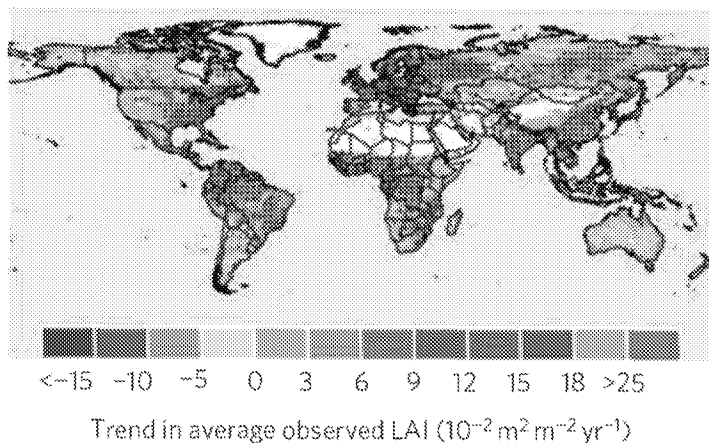


Figure 2.1: Trends in average Leaf Area Index (LAI). Source: Zhu *et al.* 2016 Figure 3.

Finally, Chen *et al.* (2024) surveyed claims that greening had slowed since 2000 due to drought stress. They found instead that faulty satellite sensors were the cause and that the corrected data showed accelerated greening over 55 percent of the globe while browning was accelerating over only 7 percent. In other words, the greening trend continued with no evidence of slowdown, and CO₂ fertilization remained the dominant driver.

2.1.2 Photosynthesis and CO₂ levels

Plants build biomass through *photosynthesis*, a process that converts carbon dioxide, water, and light into sugar. The plant enzyme responsible for photosynthesis is Ribulose-1,5-bisphosphate-carboxylase/oxygenase or “Rubisco”. Photosynthesis is initiated when CO₂ is available at the surface of the Rubisco enzyme where it is converted to a molecule with 3 carbon atoms and thereafter incorporated into plant mass. This is referred to as the “C3” process.

Rubisco is estimated to have evolved about 3 billion years ago. Over geological time the Earth’s atmospheric CO₂ levels were usually many times higher than they are today, as shown in Figure 2.2.

About 400 million years ago CO₂ levels were an estimated 2,000-4,000 ppm and were at or above 1,000 ppm for much of the interval from 200 to 50 million years ago (Berner 2006, Judd *et al.* 2024). Over the past 35 million years the level of atmospheric CO₂ has been steadily declining, falling to as low as 170 ppm during glaciations (Gerhart and Ward 2010).

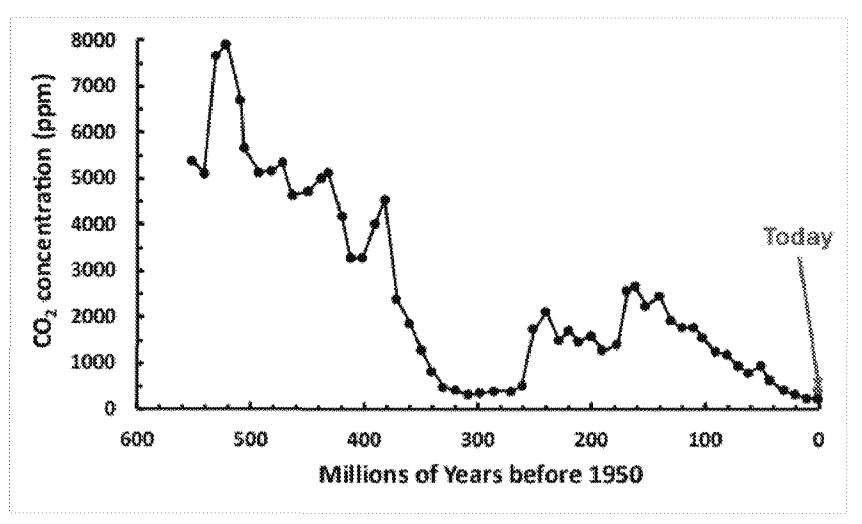


Figure 2.2. Ambient CO₂ levels over the past 550 million years. Today's concentration of 430 ppm is also shown. Source: (Berner 2006)

In response to low-CO₂ conditions some plants evolved another photosynthetic pathway called C₄, in which CO₂ is concentrated in the vicinity of Rubisco, allowing for the C₃ process to function more efficiently. For agricultural purposes the plant categories are:

- C₃: rice, wheat, soybeans and most other crops
- C₄: maize (corn), sugar cane, millet, sorghum

Had atmospheric CO₂ levels continued declining, plant growth would have declined and eventually ceased. Below 180 ppm, the growth rates of many C₃ species are reduced 40-60 percent relative to 350 ppm (Gerhart and Ward 2010) and growth has stopped altogether under experimental conditions of 60-140 ppm CO₂. Some C₄ plants are still able to grow at levels even as low as 10 ppm, albeit very slowly (Gerhart and Ward 2010).

Current CO₂ levels are about 430 ppm, up from 280 ppm in the early 1800s. The positive response of plants to extra CO₂ is illustrated in Figure 2.3, reproduced from Gerhart and Ward (2010). It shows the growth effect of CO₂ on Velvetleaf (*Abutilon theophrasti*) seedlings over 14 days under controlled conditions where only the CO₂ exposure is varied. The gains induced by increasing CO₂ from 150 ppm to 350 ppm continue under a further doubling to 700 ppm.

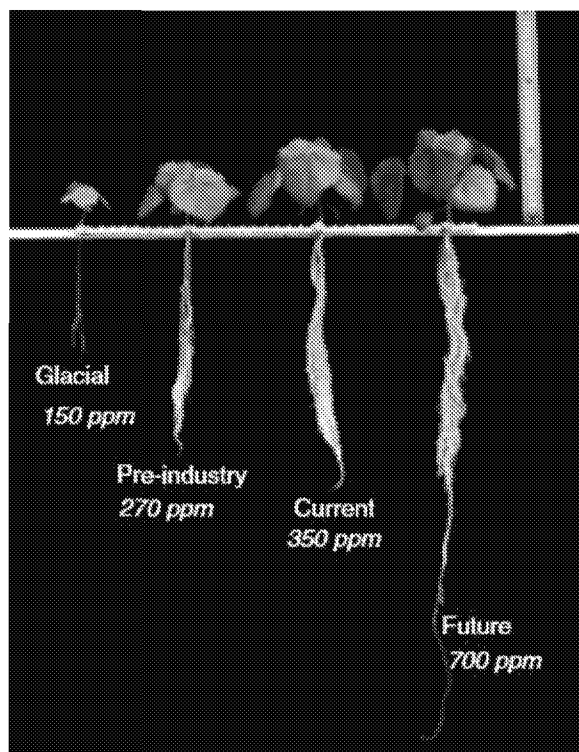


Figure 2.3: growth of *Abutilon theophrasti* after 14 days under identical conditions but for the indicated variations in CO₂ levels. Source: Gerhart and Ward (2010). Note “Current” corresponds to 1988 in image.

Over the past 60+ years there have been thousands of studies on the response of plants to rising CO₂ levels. The overwhelming theme is that plants, especially C3 plants, benefit from extra CO₂. There are two mechanisms by which CO₂ confers a growth benefit:

- Enhanced photosynthesis via the metabolic pathways described above.
- Increased water use efficiency. This arises because plants draw in CO₂ by opening the stomata (pores) on the leaf surface. When CO₂ is scarce the stomata must be kept wide open for long periods, allowing water to evaporate. Under enriched CO₂ conditions the stomata remain closed for longer periods, thus helping the plant retain water longer, and so increasing water use efficiency.

Specific effects of climate change on U.S. agriculture will be reviewed in Chapter 9.

2.1.3 Rising CO₂ and crop water use efficiency

Derying *et al.* (2016) surveyed evidence on crop water productivity (CWP), the yield per unit of water used, drawing attention to the potential for CO₂ both to enhance photosynthesis and to reduce leaf-level transpiration (water loss during leaf respiration). They surveyed all available FACE data (Free Air CO₂

Enrichment—see Chapter 9) on crop yield changes for maize (corn), wheat, rice, and soybean and combined it with crop model data simulating yield responses as of 2080 under the extreme RCP8.5 emissions scenario in four growing regions (Tropics, Arid, Temperate and Cold) each of which were split into rainfed and irrigated sub-regions. They reported that models without CO₂ fertilization predicted CWP losses in every region, but those were more than offset by CO₂ fertilization so that all regions showed a net CWP gain. Deryng *et al.* (2016) also reported that negative impacts of warming on wheat and soybean yields were fully offset by CWP gains and mitigated by up to 90 percent for rice and 60 percent for maize.

Similarly, Cheng *et al.* (2017) noted that increased global plant growth from 1982 to 2011 due to rising CO₂ uptake was accompanied by such large gains in CWP that global water use by plants had not increased, despite the extra biomass.

Deryng *et al.* (2016) assumed that climate change would “exacerbate water scarcity”. Yet while models do predict that drylands will expand under climate warming, current data show the opposite: greening is happening even in arid areas. Zhang *et al.* (2024) report that due to increased CO₂ levels “increasing aridity in drylands won’t lead to a general loss of vegetation productivity”; at most only 4 percent of currently arid areas will see increased desertification.

2.1.4 CO₂ fertilization benefits in IPCC Reports

The IPCC has only minimally discussed global greening and CO₂ fertilization of agricultural crops. The topic is briefly acknowledged in a few places in the body of the IPCC 6th and earlier Assessment Reports but is omitted in all Summary documents. Section 2.3.4.3.3 of the AR6 Working Group I report, entitled “global greening and browning,” points out that the IPCC Special Report on Climate Change and Land had concluded with *high confidence* that greening had increased globally over the past 2-3 decades. It then discusses that there are variations in the greening trend among data sets, concluding that while they have *high confidence* greening has occurred, they have *low confidence* in the magnitude of the trend. There are also brief mentions of CO₂ fertilization effects and improvements in water use efficiency in a few other chapters in the AR6 Working Groups I and II Reports.

Overall, however, the Policymaker Summaries, Technical Summaries, and Synthesis Reports do not discuss the topic.

2.2 The Alkaline Oceans

2.2.1 Changing pH

A neutral aqueous solution has a pH of 7.0, while one with pH greater than 7.0 is alkaline (also termed basic) and with pH less than 7.0 is acidic. The modern-day global average pH of sea water is estimated to be 8.04 (Copernicus Marine Service 2025), down from an estimated value of 8.2 in pre-Industrial times (Gattuso and Hansson, 2011). As CO₂ concentrations in the atmosphere increased, the oceans absorbed more, which decreases their pH. Depending upon the oceans’ buffering capacity, they are expected to become somewhat less alkaline over time, consistent with the observed decrease in pH.

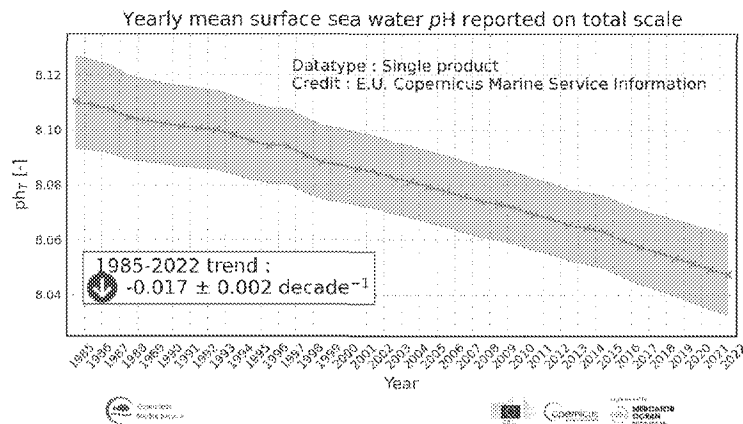


Figure 2.4: Ocean pH 1985 – 2022. Source: Copernicus Marine Service 2025

While this process is often called “ocean acidification”, it is a misnomer because the oceans are not expected to become acidic; “ocean neutralization” would be more accurate. Even if the water were to turn acidic, it is believed that life in the oceans evolved when the oceans were mildly acidic with pH 6.5– to 7.0 (Krissansen-Totton *et al.*, 2018). On the time scale of thousands of years, boron isotope proxy measurements show that ocean pH was around 7.4 or 7.5 during the last glaciation (up to about 20,000 years ago) increasing to present-day values as the world warmed during deglaciation (Rae *et al.*, 2018). Thus, ocean biota appear to be resilient to natural long-term changes in ocean pH since marine organisms were exposed to wide ranges in pH.

2.2.2 Coral reef changes

There are concerns that a decreasing pH of sea water will reduce the calcification rate of coral reefs. But coral reefs already endure large swings in pH, partly due to daily photosynthetic activity in the reef; measured pH values range from 9.4 during the day to 7.5 at night (Revelle and Fairbridge, 1957). De’ath *et al.* (2009) reported that a portion of Australia’s Great Barrier Reef (GBR, the world’s largest coral reef ecosystem) had experienced a 14 percent decline in calcification since 1990. This was tentatively attributed to increasing water temperature and decreasing pH. But Ridd *et al.* (2013) showed that report to have resulted from a biased data analysis that, when corrected, showed no change in calcification rates. Nevertheless, the alarm produced by the original paper has persisted as evidenced by the large number of published citations (541) to the original study compared to only 11 citations to the correction (as of 30 April 2025).

The most recent annual summary of GBR conditions from the Australian Institute of Marine Science indicates that coral production has rebounded strongly (AIMS, 2023). Figure 2.5 shows the results of the AIMS surveys of hard coral cover, expressed as a percentage of the reef area. Much of the decline in the GBR before 2011 turned out to be due to intense tropical cyclone activity (Beeden *et al.*, 2015) as well as a string of marine heatwaves, agricultural runoff and invasive species (Woods Hole, 2023). Given the reported declines in GBR calcification between 1990 and 2009 and the continued increase in atmospheric CO₂ levels the rebound has surprised some observers.

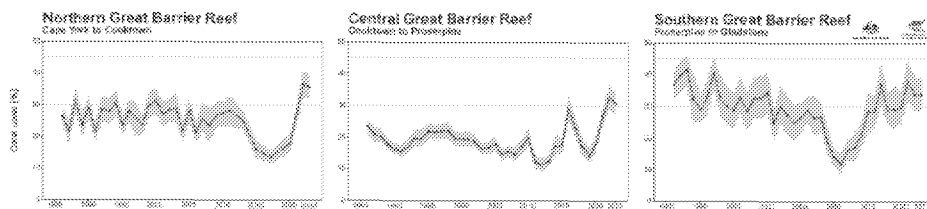


Figure 2.5 Hard coral cover of three regions of the Great Barrier Reef 1985 to 2023. Source: AIMS 2023.

It is being increasingly recognized that publication bias (alarming ocean acidification results preferred by high-impact research publications) exaggerates the reported impacts of declining ocean pH. An ICES Journal of Marine Science Special Issue addressed this problem with an article entitled, *Towards a Broader Perspective on Ocean Acidification Research*. In the Introduction to that Special Issue, H. I. Browman stated, “As is true across all of science, studies that report no effect of ocean acidification are typically more difficult to publish.” (Browman, 2016).

Similarly, a meta-analysis (Clements *et al.*, 2021) of the negative effects of ocean acidification on reef fish behavior found what they called a “decline effect”: initially dramatic conclusions published in prominent journals showing apparently large impacts of acidification tended to be followed up by subsequent studies on larger sample sizes yielding much smaller and typically non-existent effects. They call for their colleagues to improve research practices to counter the “decline effect”:

[The] vast majority of studies with large effect sizes in this field tend to be characterized by low sample sizes, yet are published in high-impact journals and have a disproportionate influence on the field in terms of citations. We contend that ocean acidification has a negligible direct impact on fish behavior, and we advocate for improved approaches to minimize the potential for a decline effect in future avenues of research (Clements *et al.*, 2021).

In summary, ocean life is complex and much of it evolved when the oceans were acidic relative to the present. The ancestors of modern coral first appeared about 245 million ago; as can be seen from Figure 2.2, CO₂ levels for more than 200 million years afterward were many times higher than they are today. Much of the public discussion of the effects of ocean “acidification” on marine biota has been one-sided and exaggerated. There is a known tendency for studies reporting dramatic effects on things like coral cover and fish behavior to get published in high-impact journals and receive widespread press coverage, then subsequent research rebutting those findings receives little attention.

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3 HUMAN INFLUENCES ON THE CLIMATE

Chapter Summary:

The global climate is naturally variable on all time scales. Anthropogenic CO₂ emissions add to that variability by changing the total radiative energy balance in the atmosphere.

The IPCC has downplayed the role of the sun in climate change but there are plausible solar irradiance reconstructions that imply it contributed to recent warming.

Climate projections are based on IPCC emission scenarios that have tended to exceed observed trends. Most academic climate impact studies in recent years are based upon the extreme RCP 8.5 scenario that is now considered implausible; its use as a business-as-usual scenario has been misleading.

Carbon cycle models connect annual emissions to growth in the atmospheric CO₂ stock. While models disagree over the rate of land and ocean CO₂ uptake, all agree that it has been increasing since 1959.

3.1 Components of radiative forcing and their history

3.1.1 Historical radiative forcing

A changing climate has been the norm throughout the Earth's 4.6-billion-year history. The Earth's temperature and weather patterns change naturally over timescales ranging from decades to millions of years. Natural variations in the surface climate originate in two ways. Internal climate fluctuations associated with circulations in the atmosphere and ocean exchange energy, water, and carbon between the atmosphere, oceans, land, and ice. External influences on the climate system include variations in the energy received from the sun and the effects of volcanic eruptions. Human activities influence climate through changing land use and land cover. Humans are also changing the composition of the atmosphere by emissions of CO₂ and other greenhouse gases and by altering the concentration of aerosol particles in the atmosphere.

The earth is warmed by the sunlight it absorbs and is cooled by the heat it radiates to space. Averaged over the Earth's surface, each of these processes involve power flows of about 240 Watts per square meter (W/m²). When they are in balance, there are no net external causes of warming or cooling. Both human and natural influences on the climate alter this balance and so cause the climate to change.

Influences on the Earth's energy balance at the top of the atmosphere are quantified by "radiative forcing", the extent to which they disturb the warming/cooling balance; a positive forcing warms while a negative forcing cools. The IPCC's estimated history of major components of radiative forcing since 1750 is shown in the following two figures from its AR6.

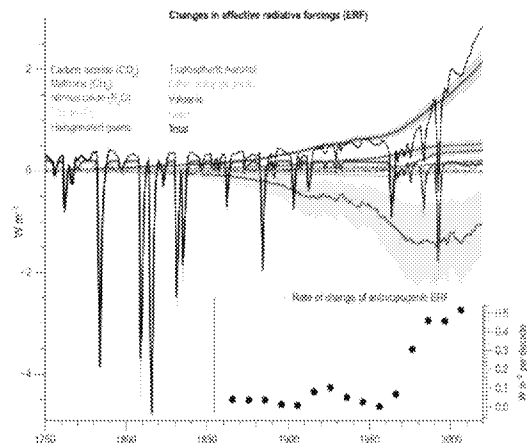


Figure 3.1.1: IPCC estimates of radiative forcing components over time. Shading indicates uncertainty ranges. Source: AR6 WGI Ch2 Fig. 10

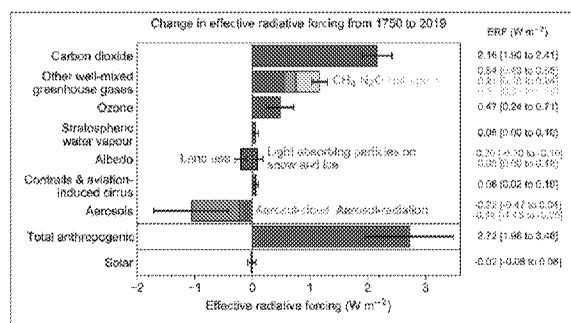


Figure 3.1.2 IPCC estimates of radiative forcing component changes from 1750 to 2019. Source: AR6 WGI Ch 7 Fig. 7-6.

These graphs show that the total radiative forcing is comprised of both natural and anthropogenic components. Carbon dioxide is the largest human influence on the climate and the one most relevant to the influence of fossil fuel use. It exerts a warming influence by decreasing the cooling power of the atmosphere. Emissions of CO₂ are accumulating in the atmosphere, as described in the following section, so that the warming influence is growing. Other greenhouse gases (methane, nitrous oxide, halogens, and ozone) act similarly, currently adding another 75 percent to CO₂'s warming. Aerosols exert an overall cooling effect, although with large uncertainties in the way they catalyze the formation of reflective clouds. As a result, understanding the causes of recent warming requires not just identifying the warming effects of CO₂, but also the more uncertain cooling effects of aerosols.

The IPCC assesses the change in the radiative forcing by the sun to be negligible, based on their preference for data reconstructions that imply minimal solar change since preindustrial times. But Connolly *et al.* (2021) reviewed sixteen different Total Solar Irradiance (TSI) reconstructions in the literature

covering the years 1600-2000; the reconstructions vary from almost no change in TSI to a relatively large upward trend. Those authors note that the variation in TSI reconstructions combined with variations in surface temperature reconstructions allows for inferences consistent with either no or most 20th century warming being attributable to the sun.

A particularly thorny issue is the gap in TSI data between 1989 and 1991 due to a delay in the launch of a monitor following the Space Shuttle Challenger disaster on January 28 1986. This delay prevented a replacement satellite from being launched in time to overlap with, and its readings to be intercalibrated with, the prior system (Zacharias 2014, Scafetta *et al.* 2019). This is called the ACRIM (Active Cavity Radiometer Irradiance Monitor) gap problem. The question of whether there is an upward trend in TSI over 1978 to 2018 hangs on how the ACRIM data gap is filled. Connolly *et al.* (2021) found that the IPCC's consensus statements on solar forcing were formulated prematurely through the suppression of dissenting scientific opinions.

Another natural radiative forcing component is volcanic aerosols, which exert an episodic cooling influence. Box 4.1 in the IPCC AR6 Report addresses the climate impact of volcanic eruptions, noting three explosive volcanic eruptions that occurred in the first half of the 19th century. This included the 1815 Tambora eruption that resulted in the 'year without summer', with multiple harvest failures across the Northern Hemisphere. There is uncertainty about the sign of the relatively small forcing due to the submarine volcano Hunga Tonga which erupted in 2022 (Jenkins *et al.* 2023, Schoeberl *et al.* 2024).

Figure 3.1.1 shows that the anthropogenic forcing component was negligible before about 1900 and has increased steadily since, rising to almost 3 W/m² today. However, this is still only about 1 percent of the unperturbed radiation flows, making it a challenge to isolate the effects of anthropogenic forcing; state-of-the-art satellite estimates of global radiative energy flows are only accurate to a few W/m².

Natural sources of global energy imbalance other than volcanoes and total solar irradiance (TSI) are not included in these graphs because they remain largely unknown.

3.1.2 Change in atmospheric CO₂ since 1958

Carbon dioxide's warming influence depends on how much "extra" CO₂ accumulates in the atmosphere- *i.e.*, its concentration above the preindustrial value of 280 ppm. The CO₂ level as recorded at the Mauna Loa observatory in Hawaii, generally used as the representative global average concentration, is available online at [HYPERLINK "<https://gml.noaa.gov/ccgg/trends/index.html>"]. The concentration was about 316 ppm at the start of the record in 1959 and is now about 430 ppm, a 36 percent increase. At the end of the last glaciation CO₂ levels had fallen to about 180 ppm. As discussed in Chapter 2, C3 plants begin dying at CO₂ levels below about 140 ppm and C4 plants at levels below 100 ppm, so if CO₂ levels had continued falling plant life would have been imperiled.

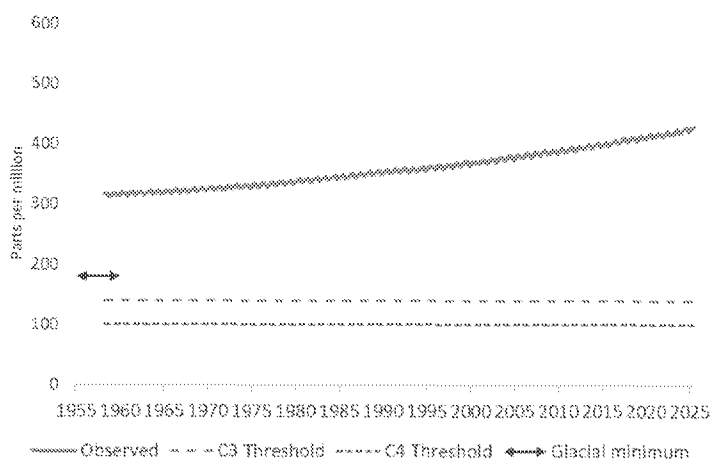


Fig. 3.1.3. Yearly average atmospheric CO₂ concentrations(1959-2025) in ppm measured at Mauna Loa (blue). C3 Threshold: Level below which C3 plants begin dying (140 ppm, see Chapter 2). C4 Threshold: Level below which C4 plants begin dying (100 ppm, see Chapter 2). Glacial minimum: Minimum level during recent glaciations (purple arrow). CO₂ data source: [[HYPERLINK "https://gml.noaa.gov/ccgg/trends/index.html"](https://gml.noaa.gov/ccgg/trends/index.html)]

The annual increase in concentration is only about half of the CO₂ emitted because land and ocean processes currently absorb “excess” CO₂ at a rate approximately 50 percent of the human emissions. Future concentrations, and hence future human influences on the climate, therefore depend upon two components (1) future rates of global human CO₂ emissions, and (2) how fast the land and ocean remove extra CO₂ from the atmosphere. We discuss each of these in turn.

3.2 Future emission scenarios and the carbon cycle

3.2.1 Emission scenarios

Assessing the dangers of future GHG emissions requires assumptions about what those emissions will be. Future emissions, and hence human influences on the climate, will depend upon future demographics, economic activity, regulation, and energy and agricultural technologies. Various assumptions about each of those lead to projections of greenhouse gas emissions and concentrations, aerosol concentrations, and changes in land use, which ultimately can be combined into assumptions about anthropogenic radiative forcing.

The great uncertainties about these many factors make it impossible to precisely predict future emissions. Instead, the IPCC has created various sets of scenarios meant to span a plausible range of possibilities for population, economy, and technologies. Recent versions of the scenarios are labeled by a number indicating the anthropogenic radiative forcing expected in 2100 under that scenario. Thus, a scenario labeled with a “6” corresponds to 6 W/m² of human-induced radiative forcing (warming) at the end of the century. (Recall current anthropogenic radiative forcing is about 2.7 W/m².)

Although the IPCC does not claim its emission scenarios are forecasts, they are often treated as such. Comparisons of past scenario groups against observations show that IPCC emission projections tend to overstate actual subsequent emissions. For the IPCC Third and Fourth Assessment Reports a set of emission projections from the *Special Report on Emission Scenarios* was used; these were referred to as the SRES scenarios. McKittrick *et al.* (2012) showed that, when converted to per capita values, the SRES scenario emissions distribution was skewed upwards and incompatible with observed trends. McKittrick and Wood (2013) further showed that global energy market dynamics constrained global per capita CO₂ emissions to an extent not reflected in IPCC scenarios. The bias of the SRES scenarios was confirmed by the later analysis of Hausfather *et al.* (2019) who showed that observed atmospheric CO₂ concentrations tracked the low end of the SRES range and also of subsequent IPCC scenario ranges (Figure 3.2.1).

For AR5 the IPCC developed a new set of scenarios called the Representative Concentration Pathways (RCPs). These were identified by a number representing the increase in forcing and were thus called RCP2.6, RCP4.5, RCP6.0 and RCP8.5. RCP2.6 (implying an anthropogenic radiative forcing in 2100 of 2.6 W/m²) describes a GHG concentration pathway leading to warming well below 2°C. At the other end of the scale RCP8.5 is an extreme outcome implying nearly 5°C warming from 1900 to 2100.

RCP8.5 came to be referred to as the no-policy baseline, or “business-as-usual” scenario in both the academic literature and popular media. It was therefore used to generate the reference outcome supposedly representing the 21st century world in the absence of increasingly stringent emission reduction policies. But RCP8.5 was intended as a low-probability high emissions scenario and its use as a business-as-usual baseline has been criticized as grossly misleading.¹ Hausfather and Peters (2020) writing in a commentary in *Nature*, pointed out that RCP8.5 was developed as an extreme worst-case, and its misuse as a “business as usual” baseline has resulted in a large number of misleading studies and media reporting.

The implausibility of the RCP8.5 scenario was examined by Burgess *et al.* (2021). They noted that RCP8.5 has already diverged from observed trends in energy use and the near future trends diverge sharply from those of the International Energy Agency (IEA), which provides market-based projections of energy use for the coming decades. The IEA trends, which are based on plausible extrapolations of current economic and demographic trends, run below the entire envelope of RCP projections, implying not only that RCP8.5 is dubious, but that even lower emission scenarios are unlikely.

Widespread use of RCP8.5 has created an alarmist bias towards alarm in the climate impacts literature. The extent of this problem was confirmed in a literature analysis by Pielke Jr. and Ritchie (2020). They found that some 16,800 scientific papers published between 2010 and 2020 used the RCP8.5 scenario, with about 4,500 of the articles linking RCP8.5 to the concept of “business-as-usual”. Their analysis showed how RCP8.5 was misused not only by individual researchers, but also by influential science agencies like the IPCC and the U.S. National Climate Assessment (USNCA), which has directly led to misleading coverage in prominent media outlets.

¹ This extreme scenario is useful for modelers, since a large forcing generates a large response (warming) making it easier to assess a model’s sensitivity. But that’s very different than claiming it is a plausible future outcome.

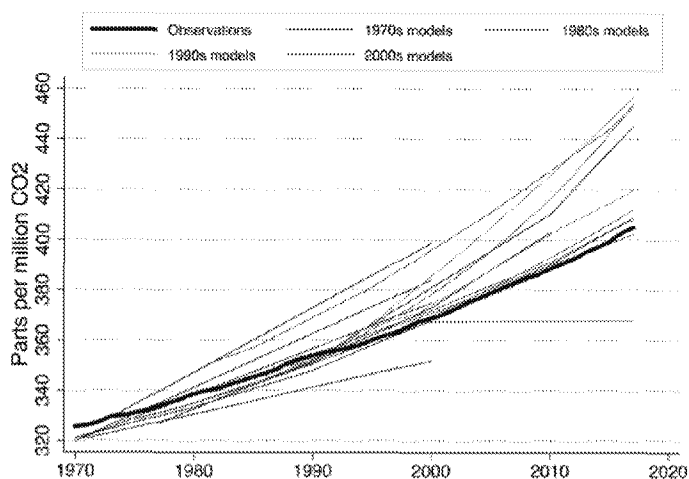


Figure 3.2.1 Comparison of observed atmospheric CO₂ levels (black line) with scenario projections (colored lines, mainly IPCC) since the 1970s. Source: Hausfather *et al.* (2019) Figure S4.

Pielke and Ritchie (2020) reported new studies using RCP8.5 were published at a rate of about 20 per day, with about two per day specifically linking RCP8.5 and “business as usual.” They conclude that the climate research community has spent a decade “committing scientific resources to science fiction” and that “The scientific literature has become imbalanced in an apocalyptic direction.”

The IPCC developed a new set of scenarios for AR6, the “Shared Socioeconomic Pathway” (SSP) scenarios, which have continued the bias shown in the RCP and SRES scenarios. Figure 3.2.2 shows total global observed CO₂ emissions compiled by the International Energy Agency (IEA) merged with the emission projection from the IEA taking account of energy use projections and current policies. The other lines show the range of IPCC SSP scenarios (SSP1-SSP5). As of 2023, global CO₂ emissions have been tracking well below SSP7.0 and are even below SSP2-4.5.

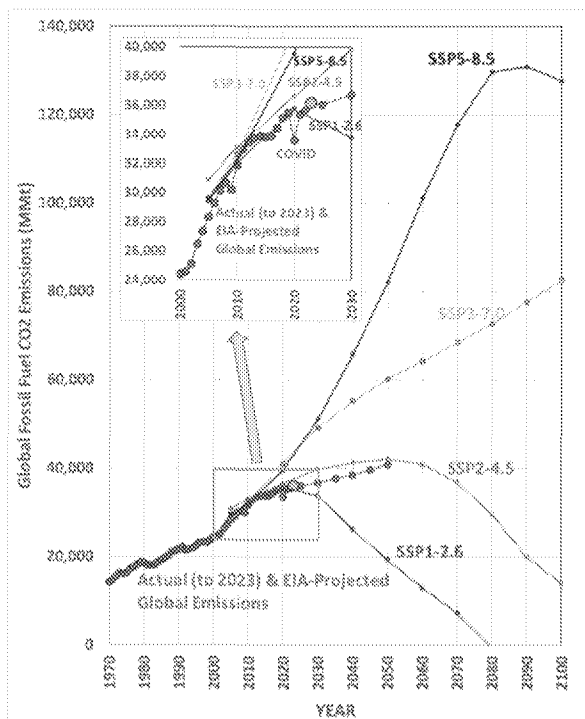


Figure 3.2.2. Observed and projected CO₂ emissions. Source: IPCC (SSP scenarios) and Energy Information Administration (EIA). Green: observed historical emissions and EIA projections. Other lines: SSP1-5. Data source: Friedlingstein *et al.* (2024).

3.2.2 The carbon cycle relating emissions and concentrations

Carbon dioxide emissions from fossil fuel burning (and to a lesser extent deforestation and cement production) have led to steadily increasing CO₂ concentrations in the atmosphere, as shown in Fig. 3.1.3. The relation between emissions and concentration is determined by the global carbon cycle of land and ocean processes that exchange carbon with the atmosphere. Our understanding of these processes was reviewed by Crisp *et al.* (2021).

There are about 850 Gt of carbon (GtC) in the Earth's atmosphere², almost all of it in the form of CO₂. Each year, biological processes (plant growth and decay) and physical processes (ocean absorption and outgassing) exchange about 200 GtC of that carbon with the Earth's surface (roughly 80 GtC with the land and 120 GtC with the oceans). Before human activities became significant, removals from the atmosphere were roughly in balance with additions. But burning fossil fuels (coal, oil, and gas) removes carbon from the ground and adds it to the annual exchange with the atmosphere. That addition (together with a much

² Because CO₂ is chemically transformed through the course of the carbon cycle, it is more convenient to track atoms of carbon rather than molecules of CO₂. One gigatonne of carbon (GtC) is equivalent to about 3.7 Gt of CO₂.

smaller contribution from cement manufacturing) amounted to 10.3 GtC in 2023, or only about 5 percent of the annual exchange with the atmosphere.

The carbon cycle accommodates about 50 percent of humanity's small annual injection of carbon into the air by naturally sequestering it through plant growth and oceanic uptake, while the remainder accumulates in the atmosphere (Ciais *et al.*, 2013). For that reason, the annual increase in atmospheric CO₂ concentration averages only about half of that naively expected from human emissions.

To project future CO₂ concentrations in the atmosphere, and hence future human influences on the climate, it is important to know how the carbon cycle might change in the future. The historical near constancy of that 50 percent fraction means that the more CO₂ humanity has produced, the faster nature removed it from the atmosphere. That 50 percent fraction changes somewhat from year to year due to natural carbon cycle imbalances from El Nino, La Nina, and varying weather patterns. There was also a substantial additional reduction in atmospheric CO₂ after the 1991 eruption of Mt. Pinatubo, a curious result that has yet to be explained (Angert *et al.*, 2004).

The main processes that remove excess CO₂ from the atmosphere are increased growth of land vegetation (especially at high latitudes), some increase in the sequestering of carbon in soils, and uptake of CO₂ by the ocean due to the increasing partial pressure of atmospheric CO₂ over that of CO₂ dissolved in the ocean. All twenty land carbon cycle models tracked by the Global Carbon Project (Friedlingstein *et al.*, 2024) show land processes have been removing excess CO₂ at an increasing rate since 1959. This is consistent with a "global greening" phenomenon (Chapter 2.1) observed by satellites since monitoring of global greenness began in 1982.

While land vegetation has been responding positively to more atmospheric CO₂, uptake of extra CO₂ by ocean biological processes remains too uncertain to be measured reliably. Our current understanding of these and many more carbon cycle processes was reviewed by Crisp *et al.* (2021).

CO₂ uptake by land processes

The uptake of extra CO₂ from the atmosphere by land surface processes (as also inferred from global greening) has been modeled with 20 different dynamic global vegetation models, the outputs of which are updated every year by the Global Carbon Project (Friedlingstein, 2024). As seen in Fig. 3.2.3, all of those models agree that vegetation and soils have been sequestering carbon from the atmosphere. But we also see that the long-term trends over 1959 to 2023 (65 years) vary widely between models, by nearly a factor of 7. This demonstrates that there remains considerable uncertainty in how fast land processes are removing CO₂ from the atmosphere, which in turn creates uncertainty in future atmospheric CO₂ concentrations, which then produce uncertainty in climate model simulations of future climate change.

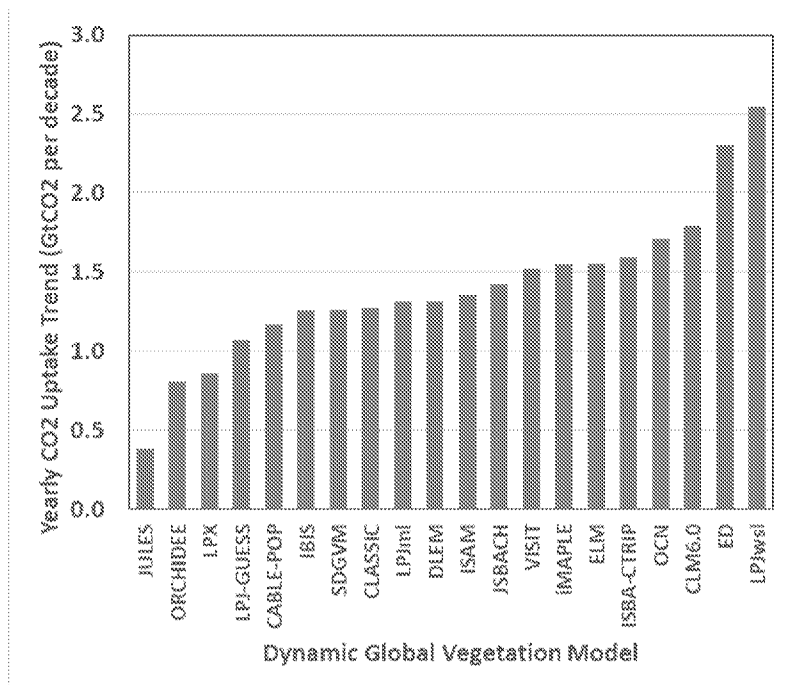


Figure 3.2.3 Trends of annual CO₂ uptake (GtCO₂ per year per decade) by land processes during 1959-2023 simulated by 20 different dynamic global vegetation models periodically reported by the Global Carbon Project (Friedlingstein, 2024).

CO₂ uptake by ocean processes

The uptake of extra CO₂ from the atmosphere by ocean processes has been modeled with 10 different ocean biogeochemistry models, the outputs of which are updated every year by the Global Carbon Project (Friedlingstein, 2024). Like the results from the land models, all of the ocean models agree that the global oceans have been sequestering carbon from the atmosphere at an increasing rate during 1959-2023 (Fig. 3.2.4). Unlike the land models, however, the ocean models show much better agreement with each other, with the model producing the fastest increasing CO₂ uptake being only 65 percent faster than the model with the most slowly increasing CO₂ uptake. In spite of the relative agreement among models, Friedlingstein *et al.* (2022) notes that there is substantial discrepancy between the different methods on the strength of the ocean sink over the last decade, particularly in the Southern Ocean.

Note that the average trend in CO₂ uptake across all land models in Fig. 3.2.3 is 25 percent larger than the average trend in ocean uptake. This suggests land processes are increasing in their ability to remove CO₂ faster than ocean processes are increasing their CO₂ sequestration.

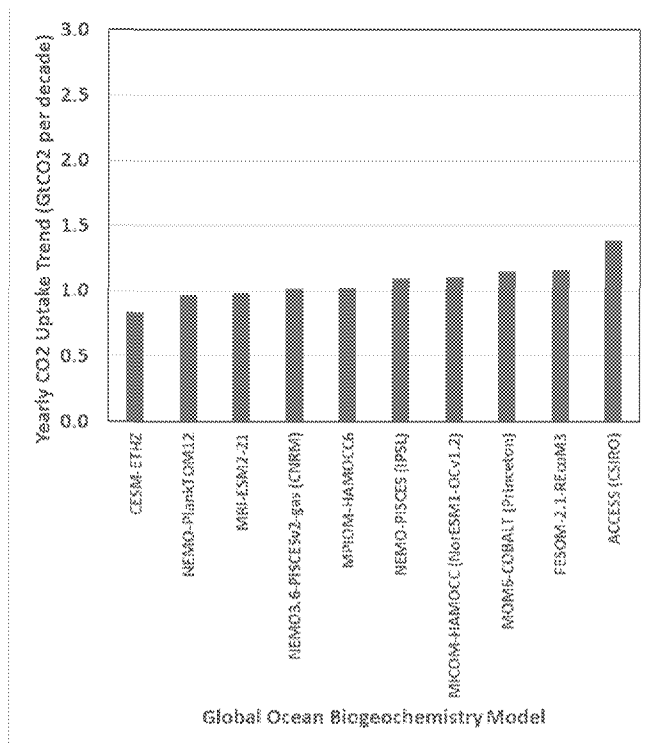


Figure 3.2.4 Trends of annual CO₂ uptake (GtCO₂ per year per decade) by ocean processes during 1959-2023 simulated by 10 different ocean biogeochemistry models periodically reported by the Global Carbon Project (Friedlingstein, 2024).

3.3 Urbanization influence on temperature trends

Historical temperature data over land has been collected mainly where people live. This raises the problem of how to filter out non-climatic warming signals due to Urban Heat Islands (UHI) and other changes to the land surface. If these are not removed the data may-might over-attribute observed warming to greenhouse gases. The IPCC acknowledges that raw temperature data are contaminated with UHI effects but claims to have data cleaning procedures that remove them. It is an open question whether those procedures are sufficient.

AR6 downplayed this issue by saying (WGI p. 235) that no recent evidence had emerged to alter the AR5 finding that urbanization causes an upward bias of no more than 10 percent in the global land surface warming trend. AR5 (WGI p. 189) also cited the 10 percent upper bound without citing a source. AR4 (WGI p. 244) cited Jones *et al.* (1990) and Peterson *et al.* (1999) as the basis of the claim. Peterson *et al.* had failed to find any difference in trends between rural and urban samples, although their definition of rural included local populations up to 10,000 persons while the relative influence of urbanization begins well below that (Spencer *et al.*, 2025). Jones *et al.* compared rural/urban warming in three regions: Eastern Australia, Eastern China and Western Soviet Union. Their definition of “rural” included towns of up to

10,000 in the former Soviet Union and up to 100,000 in China. They found relative warming biases greater than 10 percent in these areas but conjectured that the urbanization effect averaged over the areas they did not examine would bring the global land bias to under 10 percent of the observed warming trend.

Several papers appeared in print prior to the IPCC AR4 that argued that the warming effect of UHIs added a relatively large (30-50%) component to observed warming and was not simulated by climate models (de Laat and Maurellis 2006, McKittrick and Michaels 2007). These findings were based on correlations between locations of maximum warming over land with locations of maximum socioeconomic development. AR4 asserted (p. 244) that these correlations were an artefact of natural atmospheric circulations and were in fact statistically insignificant, and on that basis set the findings aside. Their claim was controversial because it was presented with no supporting evidence. McKittrick (2010) and McKittrick and Nierenberg (2010) showed that taking into account various conjectured alternative explanations for the correlations did not affect their significance. The AR5 (p. 189) conceded that the AR4 had provided “no explicit evidence” for its assessment and further acknowledged, based on these papers, that there was “significant evidence for such contamination of the record” i.e. a warming bias in the land record. However as already noted, elsewhere in the AR5 report they carried forward the AR4 claim that it was less than 10 percent of observed warming. Further they provided no caution about using the land record for climate measurement despite conceding the evidence for UHI contamination. Recently Soon *et al.* (2023) estimated an urbanization bias in the Northern Hemisphere land record over 1850-2018 sufficient to increase the trend in the blended record from 0.55°C to 0.89°C per century.

Some studies providing evidence against UHI contamination compared warming rates between rural and urban locations (Jones *et al.* 1990, Peterson *et al.* 1999, Wickham *et al.* 2013). It is not known whether such methods would be capable of detecting UHI bias even when present. The influence of UHI warming is logarithmic in population, in other words it is strongest at low population density then levels off as local urbanization expands (Oke 1973, Spencer *et al.* 2025). Hence failure to find a difference in warming rates between urban and rural stations does not prove the absence of UHI contamination. McKittrick (2013) provided an empirical demonstration in which the rural/urban trends were not significantly different in a data set shown on other grounds to be contaminated with UHI bias.

Parker (2006) examined a sample of urban locations and found no difference in trends between subsets partitioned according to nighttime wind speed, concluding on this basis that urbanization could not be a significant factor. Here again the question is whether such a method would find UHI bias even if present. McKittrick (2013) presented an example in which UHI-contaminated data did not exhibit significant trend differences when stratified according to wind speed.

The challenge in measuring UHI bias is relating local temperature change to a corresponding change in population or urbanization, rather than to a static classification variable such as rural or urban. Spencer *et al.* (2025) used newly available historical population archives to undertake such an analysis and found evidence of significant UHI bias in U.S. summertime temperature data.

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In summary, while there is clearly warming in the land record, there is also evidence that it is biased upward by patterns of urbanization and that these biases have not been completely removed by the data processing algorithms used to produce climate data sets.

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PART II: CLIMATE RESPONSE TO CO₂ EMISSIONS

4 CLIMATE SENSITIVITY TO CO₂ FORCING

Chapter Summary

There is growing recognition that climate models are not fit for the purpose of determining the Equilibrium Climate Sensitivity (ECS) of the climate to increasing CO₂. The IPCC has turned to data-driven approaches including historical data and paleoclimate reconstructions, but their reliability is diminished by data inadequacies.

Data-driven ECS estimates tend to be lower than climate model-generated values. The IPCC AR6 upper bound for the likely range of ECS is 4.0°C, lower than the AR5 value of 4.5°C. This lowering of the upper bound seems well justified by paleoclimatic data. The IPCC AR6 lower bound for the likely range of ECS is 2.5°C, substantially higher than the AR5 value of 1.5°C. This raising of the lower bound is ~~less well~~^{less} justified; evidence since the AR6 finds the lower bound of the likely range to be around 1.8°C.

4.1 Introduction

The climate's response to increasing concentrations of CO₂ is central to the scientific debate on anthropogenic climate change, and so also to the public debate on "climate action." The simplest measure of that response is the rise in the global average surface temperature, quantified by the Equilibrium Climate Sensitivity (ECS). ECS is defined as the amount of warming expected in response to a doubling of CO₂ from its pre-industrial concentration of 280 ppm, after all climate components have had time to adjust. Some components, like temperatures in the lower atmosphere (troposphere), adjust rapidly, while others such as the deep ocean and cryosphere might take as long as centuries. A related measure, the Transient Climate Response (TCR), better describes the shorter time scales; it is defined as the amount of warming when the CO₂ concentration is doubled by rising one percent annually for 70 years.

The 1979 Charney Report for the U.S. National Academy of Sciences (National Research Council 1979) proposed that the most likely ECS was $3.0 \pm 1.5^\circ\text{C}$. The IPCC repeatedly reaffirmed that range with only minor variations until its most recent AR6. AR5 termed 1.5–4.5°C as the *likely* range (66 percent probability) and stated that ECS is *extremely unlikely* (95 percent probability) to be below 1.0°C and *very unlikely* (90 percent probability) to exceed 6.5°C.

The uncertainty in ECS has remained stubbornly wide, despite many individual studies that claimed to narrow it (Hausfather 2023). Most recently, AR6 narrowed the *likely* range to 2.5–4.0°C and deemed the *very likely* range to be 2.0–5.0°C. This narrowing on the low end is disputed, as will be discussed below.

Uncertainties in ECS are highly consequential for policy making. As will be discussed in Chapter 11, economic models use ECS values to project the costs of CO₂ emissions. The traditional value (3.0 °C) has typically yielded modest global social costs of CO₂ emissions, sufficient to justify some policy actions, but mostly deferred to later in this century. If ECS is very high (above 4.5°C) immediate aggressive emission controls become more imperative, whereas no CO₂ emission controls are economically justifiable for ECS below 2.0°C (Dayaratna *et al.* 2016, 2020). Obtaining a precise estimate is impossible, so policy making needs to account for the uncertainty.

By itself, the equilibrium warming effect of a doubling of atmospheric CO₂ is slightly more than 1°C (Soden and Held 2006). Larger values of ECS arise from positive feedbacks that amplify the CO₂ warming. Water vapor feedback is positive: a warmer atmosphere ~~may~~^{might} have more water vapor, which itself is a powerful greenhouse gas. Warmer temperatures also result in less snow and sea ice cover, allowing the

Earth to absorb more of the sun’s radiation. Some simple estimates of these feedbacks increase the ECS to around 2°C (Sherwood *et al.*, 2020). Larger values of ECS are associated with positive cloud feedbacks.

Climate scientists use multiple lines of evidence to determine the Equilibrium Climate Sensitivity:

- Climate model simulations
- Historical observations
- Paleoclimatic reconstructions
- Process understanding of feedbacks

4.2 Model-based estimates of climate sensitivity

The ECS ranges given in IPCC AR4 and AR5 were obtained primarily by examining the behavior of large-scale climate models, also called General Circulation Models (GCMs). However, the IPCC changed course in its AR6 when it turned to a more direct data-driven methodology. Here we discuss some of the pitfalls of using GCMs to try to determine the Earth’s climate sensitivity.

In principle, ECS is an emergent property of GCMs – that is, it is not directly parameterized or tuned but rather emerges in the results of the simulation. But historically, collections of parameterizations have been chosen to produce an expected value of climate sensitivity, particularly with regards to sub-grid-scale cloud processes, particularly in AR4 and to a lesser extent in AR5. **THESE SENTENCES ARE CONTRADICTORY AS WRITTEN; I’VE TRIED TO FIX; AND DO WE HAVE SUPPORT FOR THE STATEMENTS ABOUT AR4,5?** Otherwise plausible GCMs and parameter selections have been discarded because of perceived conflict with this warming rate, or aversion to a model’s climate sensitivity being outside an accepted range. For example, even in a CMIP6 model, Mauritsen and Roeckner (2020) state the following regarding their Max Planck Institute (MPI) climate model (emphasis added):

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“We have documented how we tuned the MPI-ESM1.2 global climate model to match the instrumental record of warming: an endeavor which has clearly been successful. Due to the historical order of events, the choice was to do this practically by **targeting an ECS of about 3 K using cloud feedbacks**, as opposed to tuning the aerosol forcing.”

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In other words, the MPI modelers chose an ECS value of 3°C and then tuned the cloud parameterizations to match their intended result.

As noted, direct warming from CO₂ doubling is only about 1°C (Soden and Held 2006); further warming arises from climate feedbacks that are not explicitly resolved by the GCM but rely on parameterizations of physical processes. Higher values of ECS arise primarily from assumed positive cloud feedbacks, whereas the magnitude and even the sign of the feedbacks are very uncertain. Elements of cloud feedback include changes in the latitudinal distribution of clouds, changes in the distribution of cloud height (changes in low versus high clouds), changes to the phase of clouds (ice versus liquid), changes in cloud particle size (associated with changes in concentration and/or composition of aerosol particles), changes in the precipitation efficiency of clouds, and even changes in how clouds are distributed over the daily solar cycle (Curry and Webster, 1999). It is difficult for GCMs to simulate any of these processes correctly owing to their small scale, let alone predict how they will change in the future. Further, cloud processes modulate the magnitudes of the water vapor, lapse rate, and the surface albedo feedbacks.

ECS can be determined from climate model simulations by doubling the concentration of CO₂ and allowing several centuries for the warming to equilibrate. To avoid the necessity-need for of such long

simulations, “effective climate sensitivity” is commonly evaluated from a 150-year simulation in response to a sudden quadrupling of CO₂.

The spread of ECS values from the CMIP5 ensemble of climate models used in the AR5 was 2.0–4.7°C; that range increased for the CMIP6 models used in the AR6 to between 1.8 and 5.7°C (Chen *et al.*, 2021, Scafetta 2021, see Figure 4.1). Far from settling the model-based sensitivity of climate system, uncertainties appear to be growing. The main cause of the overall upward shift in ECS in CMIP6 relative to CMIP5 is a larger positive cloud feedback, driven by changes to the cloud parameterizations in many CMIP6 models (Zelinka *et al.*, 2020)

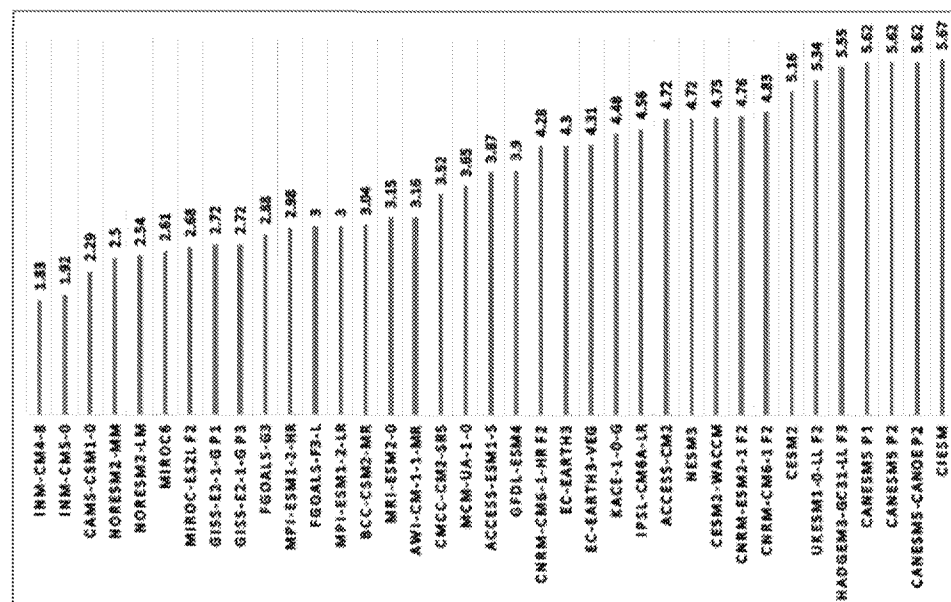


Figure 4.1 Equilibrium Climate Sensivities in °C of 37 climate models from the CMIP6 ensemble. Identifiers for the various models appear along the horizontal axis. From (Scafetta, 2021)

Because of concerns about model tuning and the high sensitivity to cloud parameterizations, the IPCC AR6 (2021) did not rely on climate model simulations in their assessment of climate sensitivity, relying instead on data-driven methods.

4.3 Data-driven estimates of climate sensitivity

Climate sensitivity can also be estimated from instrumental records of surface temperatures and ocean heat content, combined with estimates of how climate forcings (e.g., greenhouse gases, solar, volcanoes, aerosols) have changed in the past (Otto *et al.*, 2013). Using this information, a simple empirical model

called an Energy Balance Model can be employed. It requires estimating a feedback parameter whose uncertainties are highly amplified in the resulting ECS (Roe and Baker, 2007).

The accuracy of the data-driven methods depends on the quality of the input data. Assumptions are needed about ocean heat storage, and good data is only available for recent decades. The greatest source of uncertainty is the amount and composition of aerosol particles and their interactions with cloud radiative properties (the so-called aerosol indirect effect; see Figures 3.1.1, 3.1.2). Climate models exhibit warming in response to GHGs but cooling in response to aerosols (Schwartz *et al.*, 2007). Observed 20th century warming can be shown to be consistent either with low ECS and low aerosol cooling, or high ECS and high aerosol cooling. Since fossil fuel use adds both GHGs and aerosols to the atmosphere, both effects need to be estimated to isolate the warming effect of CO₂.

Paleoclimate proxies are also used to evaluate the sensitivity of past climates by comparing paleoclimate changes in the Earth's temperatures to estimates of changes in forcings. The two most informative periods are the last glacial maximum (around 20,000 years ago), which was about 3–7°C colder than today, and a mid-Pliocene period (roughly three million years ago), which was 1–3°C warmer than today. The limits on cooling during the last glacial maximum give the best single evidence that high values of climate sensitivity are unlikely. However, paleoclimate estimates are associated with very large uncertainties in the estimated temperatures and forcings. Further, estimates of climate sensitivity based on past climate states ~~may-might~~ not be applicable to the current state of the climate system.

A recurring theme in the climate literature is that ECS estimates based on historical data are smaller than ECS estimates inferred from climate models (Sherwood and Forest 2024). About 15 estimates based on historical data appeared in the peer-reviewed literature between 2012 and 2024 yielding ECS best estimates between 1.0°C and 2.5°C, although critics have questioned some of the methods and the data quality. For the AR6, the IPCC placed primary weight on the results of Sherwood *et al.* (2020) that combined historical data and paleoclimate proxies with the process-based approach and yielded a best estimate of 3.1°C with a *likely* range of 2.6–3.9°C. Lewis (2022) raised a number of concerns about this result, including methodological errors, outdated input values, and use of subjective Bayesian priors in the analysis. Lewis' analysis found that climate sensitivity is estimated to be much lower and better constrained than in the Sherwood *et al.* analysis – median 2.2°C (1.8–2.7°C in the 17–83 percent *likely* range, and 1.6–3.2°C in the 5–95 percent *very likely* range). The IPCC AR6 estimated only a 5 percent probability that ECS was below 2.3°C, whereas Lewis estimated it to be over 50 percent. The most recent publications on the debate between Sherwood *et al.* and Lewis further defend their respective positions: Sherwood and Foster (2024) and Lewis (2025).

An argument emphasized in AR6 is that data-driven ECS estimates might understate the future warming response to GHGs because of a so-called “pattern effect” (Forster *et al.*, 2021). The tropical Pacific is believed to strongly influence the overall efficiency with which the Earth radiates heat to space, but some regions remove heat more efficiently than others. If the west-to-east temperature gradient in the tropical Pacific is weakened in a warming climate, warming would concentrate where heat is less efficiently removed, raising ECS.

Most climate models simulate that rising GHGs will weaken the west-east temperature gradient, which led the IPCC in the AR6 to conclude that data-driven ECS estimates understated the *future* ECS value. However, Seager *et al.* (2019) pointed out that, contrary to models, the west-east temperature gradient has been strengthening over time. They further argued that the mechanism predicting otherwise in climate models was based on a faulty characterization of oceanic dynamics and there is no reason to expect the gradient to weaken. A similar argument was recently made by Lee *et al.* (2024), who concluded that “the trajectory of the observed trend reflects the response to increasing GHG loading in the atmosphere”; in other words, GHG warming should lead to a future strengthening rather than a weakening of the temperature gradient. Increased efficiency of atmospheric cooling implies, if anything, that the future ECS in a warming climate ~~may-might~~ be *lower* than current estimates.

4.4 Transient Climate Response

The Transient Climate Response (TCR) provides a more useful observational constraint on climate sensitivity. TCR is the global temperature increase that results when CO₂ is increased at an annual rate of 1 percent over a period of 70 years (*i.e.*, doubled gradually). Relative to the ECS, observationally determined values of TCR avoid the problems of uncertainties in ocean heat uptake and the fuzzy boundary in defining equilibrium arising from a range of timescales for the longer-term feedback processes (*e.g.*, ice sheets). TCR is more generally related to peak warming and better constrained by historical warming than ECS. IPCC AR6 judged the *very likely* range of TCR to be 1.2–2.4°C. In contrast to ECS, the upper bound of TCR is more tightly constrained. For comparison, the TCR values determined by Lewis (2023) are 1.25 to 2.0°C, showing much better agreement with the AR6 values than was seen in a comparison of the ECS values.

As will be discussed in Chapter 5, a real-world ECS smaller than the model average is supported by studies that show climate models on average overestimate the observed surface and troposphere warming over the past 50 years. Lower sensitivities also align with evidence from consistent fingerprinting (Chapter 8), where model responses need to be downscaled to align with observed trends. ~~DOESN'T BELONG IN TCR SECTION NOT NEEDED IN THIS CHAPTER~~

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5 MODELS VERSUS OBSERVATIONS IN THE RECENT PAST

Chapter summary

Climate models show warming biases in many aspects of their reproduction of the past several decades. In response to estimated changes in forcing they produce too much warming at the surface (except in the models with lowest ECS), too much warming in the lower-and mid-troposphere and too much amplification of warming aloft.

Climate models also produce too much recent stratospheric cooling, invalid hemispheric albedos, too much snow loss, and too much warming in the Corn Belt. The IPCC has acknowledged some of these issues but not all.

5.1 Introduction

Climate models are the primary tool used to project future climate changes in response to increasing atmospheric levels of anthropogenic greenhouse gases. To assess the fitness of climate models for this purpose, it is reasonable to ask how well they reproduce the current climate and its variations over the past century. The box “Climate modeling” gives some detail on how climate models work.

Of great concern is the fact that, after several decades of the climate modeling enterprise involving approximately three dozen models operated by research centers around the world, the range of future warming they produce in response to a hypothetical doubling of atmospheric CO₂ extends over a factor of three, as we discussed in the previous chapter. This range of disagreement among models has not decreased for decades.

Problems with climate models are not just in their disagreement over the future, but also in their ability to replicate the recent past. Here we review some of the most important metrics of climate model accuracy: ability to reproduce historical surface, tropospheric and stratospheric temperature trends; ability to reproduce the vertical warming profile; and ability to reproduce other climate features such as snowfall. In all cases a persistent finding is that models on average err on the side of too much warming in response to estimated historical forcings.

BOX: Climate modeling

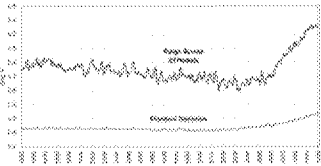
Most climate models, except for the simplest ones, represent Earth's land surface using a grid of squares on the order of 100 km wide. To simulate the atmosphere, typically 30 or more grid boxes are stacked above these squares. The ocean is modeled using a similar but finer grid, resulting in tens of millions of grid boxes for the atmosphere and oceans.

The computer models, based on physical laws, calculate how air, water, and energy move between grid boxes over time. The time step can be as small as 10 minutes, and repeating this process millions of times allows the simulation of climate over centuries. Running these models, even on the most powerful supercomputers, can take months. Comparing simulation results with historical climate data helps assess the accuracy of a model, while projections into the future estimate climate changes under assumed human and natural influences.

Despite sounding straightforward, climate modeling is highly complex. Many critical processes occur at scales smaller than the grid size. For instance, the flows of sunlight and heat in the atmosphere depend strongly on cloud cover. Since tracking individual clouds is impractical, researchers must make "subgrid" assumptions about the distribution of clouds in each grid box. Snow and ice cover, which affects how much sunlight is reflected or absorbed by the surface, is another subgrid factor.

Each subgrid assumption requires numerical parameters, which must be carefully set. Modelers initially estimate these parameters based on physics and observed climate patterns, then run the model. Because early results often diverge significantly from real-world observations, they "tune" these parameters to better match observed climate features. Different modeling teams use distinct assumptions and tuning strategies, leading to varied outcomes. Tuning is a necessary but delicate aspect of climate modeling, as it is for any complex system. Poor tuning can result in inaccurate simulations, while excessive tuning risks artificially steering results toward predetermined conclusions.

The spread of model indicators—Earth's 1880 (Figure 5.1), warming was only processes.



very wide. One of the most basic about 3°C across CMIP6 models prior to to over 4 °C. For comparison 20th century tantial differences among models' physical

Figure 5.1 CMIP6 Average surface temperature range across 33 models and standard deviation using SSP5-85 scenario. Data from KNMI Climate Explorer website at [[HYPERLINK "https://climexp.knmi.nl/start.cgi"](https://climexp.knmi.nl/start.cgi) \t "_blank"].

Beyond the models' ability to reproduce features of today's climate, the critical issue for society is how well they predict responses to subtle human influences, such as greenhouse gas emissions, aerosol cooling, and land-use changes. The most crucial aspect that models must capture correctly is "feedbacks." These occur when climate changes either amplify or suppress further warming. In general, the modeled net effect of all feedbacks doubles or triples the direct warming impact of CO₂.

5.2 Surface warming

A straightforward test of a climate model's validity is its ability to reproduce historical warming in response to known past changes in climate drivers such as greenhouse gases. Figure 5.2 is reproduced from Scafetta (2023), that groups the latest-generation (CMIP6) climate models into low ECS (1.5 to 3.0 degrees C), medium ECS (3.0 to 4.5 degrees C) and high ECS (4.5 to 6.0 degrees C), and compares their post-1980 global average temperature simulation ranges to those of three surface temperature records and one satellite-based lower troposphere temperature data product.

The leftmost column shows that the low-ECS models track the post-1980 historical warming record reasonably well, but the middle and right columns show that the medium- and high-ECS models conspicuously over-predict the warming.

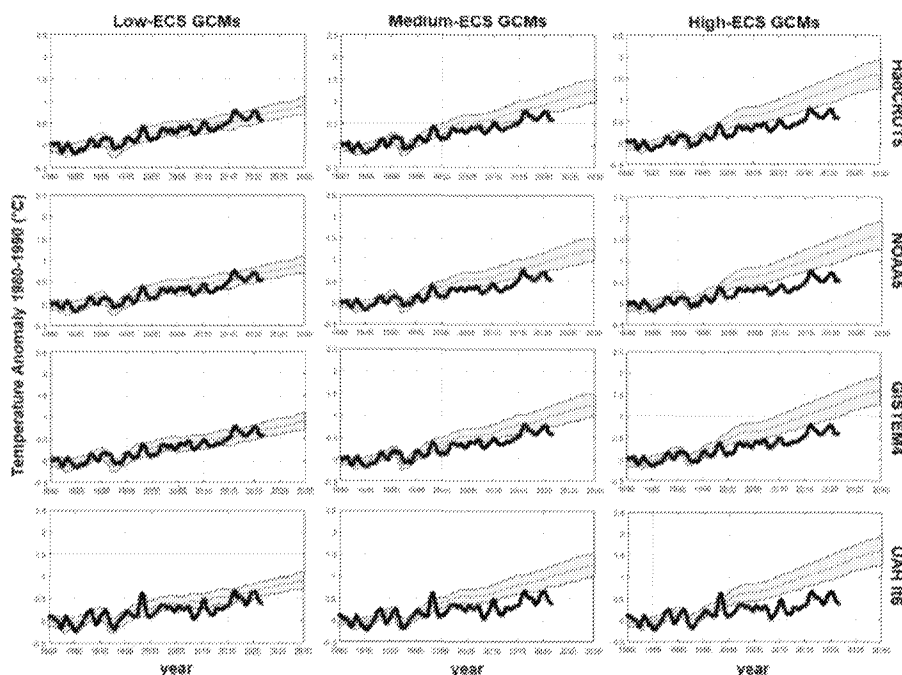


Figure 5.2: Model-Observational comparisons for Earth's surface warming. The columns correspond to model groups showing low-ECS to high-ECS, while the rows correspond to widely-used observed temperature records, the first three showing surface averages and the fourth showing the lower troposphere average. In each panel the yellow area denotes the mean and range ($\pm$ one standard deviation) of climate model simulations for that group. The thick black line shows the observed annual average temperature in the indicated source. Source: Scafetta (2023) Fig.2.

Spencer (2024) has also provided a useful summary of the Model-Observation mismatch by comparing trends in surface temperature data products with those in individual climate models, as summarized in Figure 5.3. It is seen that most climate models show substantially more warming than the observations.

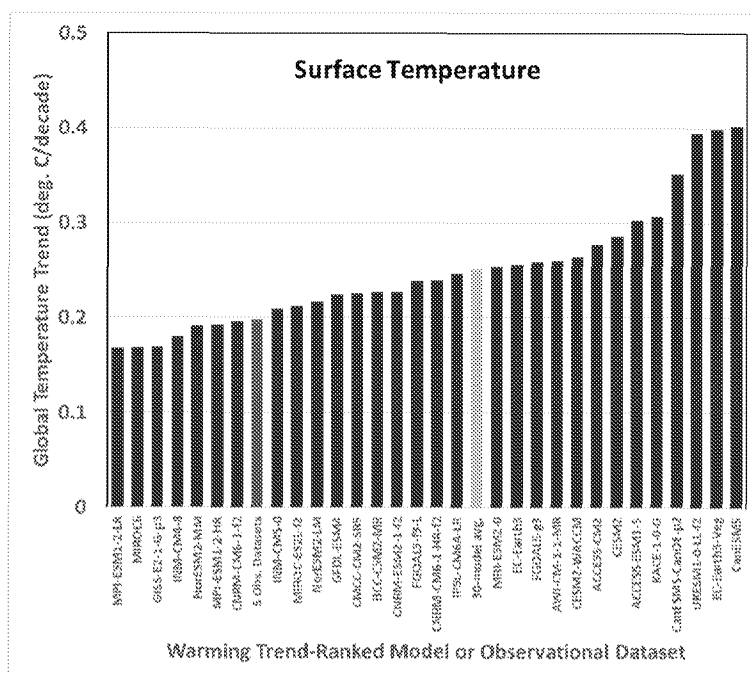


Figure 5.3 Global surface air temperature trends (°C/decade), 1979-2024, from various CMIP6 climate models (red, 30-model average in orange); and the average of three thermometer datasets (HadCRUT5, NOAA Global Temp, and Berkeley 1 deg.) and two reanalysis datasets (ERA5 and NCEP/NCAR R1) in blue. Data source: <https://climexp.knmi.nl/start.cgi>.

5.3 Tropospheric warming

It has long been known that climate models on average overstate warming in the tropical troposphere. This region is an important test of climate models since this is where the signal of anthropogenic greenhouse warming emerges first and most strongly. Biases in tropospheric trends indicate model flaws in heat transfer processes that carry over to surface warming biases.

The discrepancy was flagged as a serious inconsistency in the first U.S. Climate Change Science Program report (Karl *et al.* 2006) and has been mentioned in every IPCC report since, but the discrepancy has gotten worse over time, and the bias is now global. McKittrick and Christy (2020) compared tropospheric warming trends in CMIP6 climate models to observed trends from satellites, weather balloons and reanalysis systems. Every model overpredicted the average observed warming trend over 1979-2014 in both Lower- and Mid-Troposphere layers, both globally and in the tropics. In most individual models the bias was statistically significant and on average across models it was highly significant.

Figure 5.4 presents the comparisons with data updated to 2024 (McKittrick and Christy 2025). The recent warm years moved the observed trend up slightly and widened the trend confidence intervals but the overall pattern remains the same: model bias is towards too much warming, in most cases the difference is statistically significant and on average the bias is statistically highly significant. McKittrick and Christy (2020) also showed that the bias is larger in high-ECS models, but even the models with lower average ECS predict too much warming. If future climate models were to realistically represent global tropospheric warming, they would likely be less sensitive than even the low-ECS members of the CMIP6 ensemble.

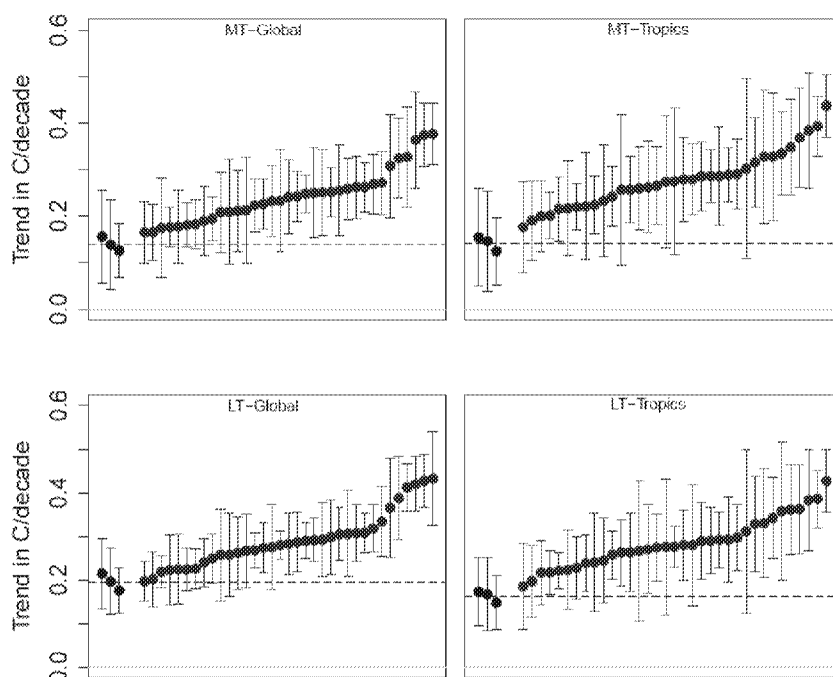


Figure 5.4: Observed versus CMIP6 modeled warming trends (°C/decade 1979-2024) in the global and tropical lower (LT) and mid-troposphere (MT). Uses methodology of McKittrick and Christy (2020) on data updated from 2014 to 2024. Blue dots: warming trends with 95 percent confidence intervals for 3 data products (radiosondes, reanalysis, and satellites). Blue dashed line: warming trend average for 3 observed series. Red dots: modeled warming trends with 95 percent confidence intervals in 35 models arranged lowest to highest.

As mentioned previously, the IPCC has long acknowledged the model-observation mismatch. For example, AR6 pp. 443-444 offers this on the tropical troposphere (it does not address the global comparison):

Several studies since AR5 have continued to demonstrate an inconsistency between simulated and observed temperature trends in the tropical troposphere, with models simulating more warming than observations (Mitchell *et al.*, 2013, 2020; Santer *et al.*, 2017a, b; McKittrick and Christy, 2018; Po-Chedley *et al.*, 2021). ... Over the 1979–2014 period, models are more consistent with observations in the lower troposphere, and least consistent in the upper troposphere around 200 hPa, where biases exceed 0.1°C per decade. Several studies using CMIP6 models suggest that differences in climate sensitivity may be an important factor contributing to the discrepancy between the simulated and observed tropospheric temperature trends (McKittrick and Christy, 2020; Po-Chedley *et al.*, 2021), though it is difficult to deconvolve the influence of climate sensitivity, changes in aerosol forcing and internal variability in contributing to tropospheric warming biases (Po-Chedley *et al.*, 2021). Another study found that the absence of a hypothesized negative tropical cloud feedback could explain half of the upper troposphere warming bias in one model (Mauritsen and Stevens, 2015). ~~I DON'T THINK THIS PARA IS NEEDED? FOLLOWING PARA PACKS A BIGGER PUNCH PER ROSS' RECENT EMAIL, WE'LL KEEP IT~~

... In summary, studies continue to find that CMIP5 and CMIP6 model simulations warm more than observations in the tropical mid- and upper-troposphere over the 1979–2014 period (Mitchell *et al.*, 2013, 2020; Santer *et al.*, 2017a, b; Suárez-Gutiérrez *et al.*, 2017; McKittrick and Christy, 2018), and that overestimated surface warming is partially responsible (Mitchell *et al.*, 2013; Po-Chedley *et al.*, 2021). ... Hence, we assess with *medium confidence* that CMIP5 and CMIP6 models continue to overestimate observed warming in the upper tropical troposphere over the 1979–2014 period by at least 0.1°C per decade,

Notably, despite the accumulation of evidence of excess model warming the IPCC assigns only ~~assigns~~ *medium confidence* to the existence of a warming bias.

5.4 Vertical temperature profile mismatch

Another important model-observational discrepancy is the excess amplification with altitude found in climate models. The comparison was in the IPCC AR5 Chapter 10, although only in the online supplement (Figure 10.SM.1) and only in a figure whose formatting obscured the point. Figure 10.SM.1 is not referenced in the main IPCC report nor in any summary so readers would not have been aware of it. Although not apparent at first glance, it shows that the 1979–2010 warming in the lower troposphere is so small as to be consistent with no GHG forcing at all and is inconsistent with the model runs that do have GHG forcing. In Figure 5.6 we adapt IPCC AR5 Figure 10.SM.1 to draw out this critical point.

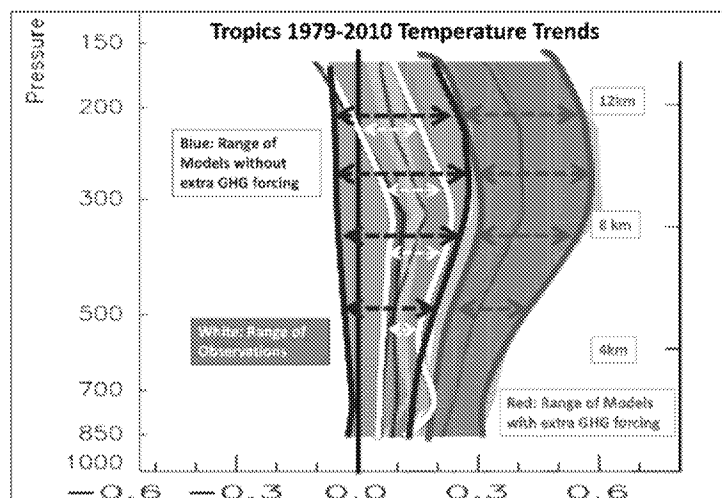


Figure 5.6: Vertical warming pattern for tropics (20S to 20N). Source: Annotated version of IPCC AR5 Figure 10.SM.1

Figure 5.6 compares model and observational temperature trends by altitude between 20S and 20N (the tropics). In this region where the models say the warming should be strongest, the observations (shown here in white) lie within the blue “No CO₂” band and entirely outside the “with CO₂” red envelope. This means that in the entire tropical atmospheric column from the surface to the base of the stratosphere, observed warming trends are so small as to be consistent with the output of models that have no anthropogenic CO₂ warming, and inconsistent with the entire envelope of warming trends generated by models forced with increased CO₂.

A similar comparison is shown in Christy and McNider (2017), an updated version of which (covering 1979-2024) is reproduced as Figure 5.7. Modeled temperature trends exceed observations from the surface through the top of the troposphere, with observed trends below the entire model range at most pressure levels. Also shown in Figure 5.7 is the tropical tropospheric temperature (TTT) average from three satellite data products (NOAA, UAH and RSS) compared to the same layer average from climate models for 1979-2024. Again, the observed trends lie below the entire model range.

The wide range of choices made by modelers to characterize the physical processes in the models (see Box: Climate Modeling in Section 5.1 above) is seen by the large spread of trends in the middle troposphere, ±40 percent about the median (Fig. 5.7). This vividly illustrates the uncertainties in attempts to model (parameterize) a complex system involving turbulence, moist thermodynamics, and energy fluxes over the full range of the tropical atmosphere’s time and space scales.

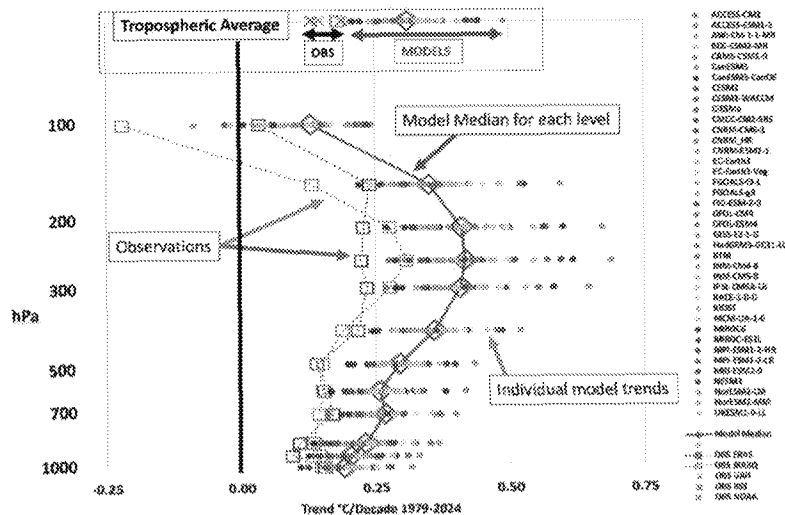


Figure 5.7: Modeled versus observed warming, tropical troposphere. Source: updated from Christy and McNider (2017) including data through 2024. Red line: model average. Green and blue lines: observational series (reanalysis).

This discrepancy has been the source of much controversy, with some arguing that even if there is very little observed warming aloft in the tropics, a “hotspot” still exists in the sense that the warming aloft is greater than at the surface (Santer et al. 2008). But there is good evidence that models also exaggerate the amplification rate. Klotzbach *et al.* (2009), showed that models project greater amplification with altitude than is observed. This result was subsequently confirmed by detailed time series analysis (Vogelsang and Nawaz 2016) ~~who~~ which found that the model-observational difference is statistically significant.

The atmosphere’s temperature profile is a case where models are not merely uncertain but also show a common warming bias relative to observations. This suggests that they misrepresent certain fundamental feedback processes.

The IPCC AR6 did not assess this issue.

5.5 Stratospheric cooling

An important element of the expected general “fingerprint” of anthropogenic climate change is simultaneous warming of the troposphere and cooling of the stratosphere. The IPCC AR6 acknowledged that cooling had been observed but only until the year 2000. The stratosphere has shown some warming since, contrary to model projections.

The AR6 WG1 Ch 2 pp. 327-9 states:

Temperatures averaged through the full lower stratosphere (roughly 10–25 km) have decreased over 1980–2019 in all data products, with the bulk of the decrease prior to 2000. The decrease holds even if the influence of the El Chichon (1982) and Pinatubo (1991) volcanic eruptions on the trend,

found by Steiner *et al.* (2020a) to have increased the 1979–2018 cooling trend by 0.06°C per decade, is removed. Most datasets show no significant or only marginally significant trends over 2000–2019, and the results of Philipona *et al.* (2018) show weak increases over 2000–2015 in the very lowermost stratosphere sampled by radiosondes...

It is virtually certain that the lower stratosphere has cooled since the mid-20th century. However, most datasets show that lower stratospheric temperatures have stabilized since the mid-1990s with no significant change over the last 20 years. It is likely that middle and upper stratospheric temperatures have decreased since 1980, but there is low confidence in the magnitude.

The cited source, Philipona *et al.* (2018), in an article entitled “Radiosondes Show That After Decades of Cooling, the Lower Stratosphere Is Now Warming”, stated:

In response to continued greenhouse gas increases and stratospheric ozone depletion, climate models project continued tropospheric warming and stratospheric cooling over the coming decades. Global average satellite observations of lower stratospheric temperatures exhibit no significant trends since the turn of the century. In contrast, an analysis of vertically resolved radiosonde measurements from 60 stations shows an increase of lower stratospheric temperature since the turn of the century at altitudes between 15 and 30 km and over most continents. Trend estimates are somewhat sensitive to homogeneity assessment choices, but all investigated radiosonde data sets suggest a change from late twentieth century cooling to early 21st century warming in the lower stratosphere.

A combination of tropospheric warming and stratospheric cooling is a ~~commonly-cited~~commonly cited “fingerprint” of anthropogenic warming. Stratospheric warming since 2000 coincides with continued surface and tropospheric warming, a pattern that is not found in climate model simulations and is not apparently consistent with the anthropogenic fingerprint.

5.6 Snow cover mismatch

Data compiled by the Rutgers University SnowLab ~~show~~Lab show that Northern Hemisphere winter snow cover is not decreasing (Figure 5.8); if anything, it shows an increasing trend.

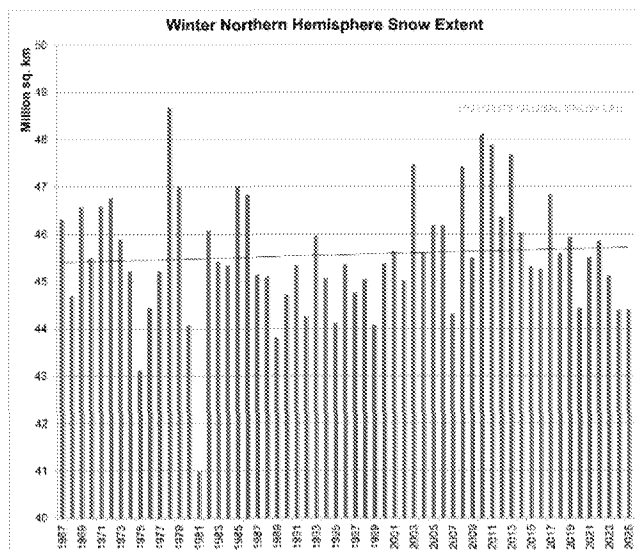


Figure 5.8: Northern Hemisphere Winter Snow extent.

Source: [[HYPERLINK](https://climate.rutgers.edu/snowcover/chart_seasonal.php?ui_set=nhland&ui_season=1)

"https://climate.rutgers.edu/snowcover/chart_seasonal.php?ui_set=nhland&ui_season=1"]
(accessed May 27, 2025)

Yet models project declining Northern Hemisphere snow cover in a warming climate, as described by Connolly *et al.* (2019).

The climate models were found to poorly explain the observed trends [in Northern Hemisphere snow cover]. While the models suggest snow cover should have steadily decreased for all four seasons, only spring and summer exhibited a long-term decrease, and the pattern of the observed decreases for these seasons was quite different from the modelled predictions. Moreover, the observed trends for autumn and winter suggest a long-term increase, although these trends were not statistically significant.

AR6 largely confines its discussion of changing Northern Hemisphere snow cover extent (SCE) to the Spring season, for which models and observations agree on a downward trend. Regarding Winter changes it remarks as follows (AR6 WGI Ch. 2 p. 344):

Assessment of SCE trends in the NH since 1978 indicates that for the October to February period there is substantial uncertainty in trends with the sign dependent on the observational product. Analysis using the NOAA Climate Data Record shows an increase in October to February SCE (Hernández-Henríquez *et al.*, 2015; Kunkel *et al.*, 2016) while analyses based on satellite borne optical sensors (Hori *et al.*, 2017) or multi-observation products (Mudryk *et al.*, 2020) show a negative trend for all seasons.

AR6 WGI Chapter 9 (p. 1284) points out that the NOAA Climate Data Record showing increased fall and winter SCE is inconsistent with land-based observations and model-based data sets. It notes that using optical satellite imagery to infer SCE in winter is challenging due to cloud cover and decreased solar illumination in winter months. Focusing on the Pacific Coast states (CA, OR and WA) cold season mountain snowfall that melts in spring and summer provides a substantial portion of warm season water resources. A comprehensive reconstruction of snowfall for the main source regions (Cascades and Sierra Nevada Mountains) indicates no significant trends in annual totals since the late 19th century (Christy 2022).

In summary, the up-to-date Rutgers SCE database indicates a mismatch between models and observations. Further work to reconcile conflicting trends in observational data sets is required.

5.7 Hemispheric symmetry of the planetary albedo

The planetary albedo is the fraction of incoming solar radiation reflected by the Earth back to space. It is an important element of the radiative energy balance and influences whether the planet will warm or cool over time. The planetary albedo is typically estimated at around 0.30; variations on the scale of 0.01 correspond to changes in solar forcing of about 3 W/m^2 , an amount larger than current anthropogenic forcing. It has long been noted that models disagree with each other and with observations on the value of the global planetary albedo (Stephens *et al.* 2015).

An intriguing property of the Earth's albedo is that, on average, the Northern Hemisphere (NH) and Southern Hemisphere (SH) have had nearly the same albedo, at least throughout the fifty-year satellite record (Stephens *et al.*, 2015). This symmetry is surprising, because the SH has much more ocean than land. Since ocean is less reflective than land, the NH should have higher albedo. Clouds (which are highly reflective) are more common in the NH and so compensate the surface albedo imbalances of the two hemispheres. Datseris and Stephens (2021) show that this cloud compensation comes from the extra-tropical storm tracks of the SH, which are cloudier than those of the NH. While the mechanism for this hemispheric symmetry is unclear, it likely operates on large temporal and spatial scales.

The hemispheric symmetry of the albedo is a simple gross metric for climate models. Rugenstein and Hakuba (2023) defined that metric as the difference between the NH and SH annual mean albedos, expressed as Wm^{-2} of the reflected sunlight, and compiled it for the CMIP6 climate models, as shown in Figure 5.9. Most of the CMIP6 models do not reproduce the small observed asymmetry (about 0.1 Wm^{-2}) and even disagree as to which hemisphere is more reflective. Moreover, the magnitude of the asymmetry ranges up to 5 Wm^{-2} in some models, twice as large as the current anthropogenic forcing (about 2.5 Wm^{-2}).

The significance of unphysical albedo asymmetries in the climate models is not yet fully known. However, other model studies suggest that interhemispheric changes in albedo can alter poleward heat fluxes, meridional temperature gradients, storminess, and differences in hemispheric ocean heat storage. The discrepancy between models and observations further raises issues regarding cloud feedback processes and so more generally diminishes confidence in model projections of the future climate.

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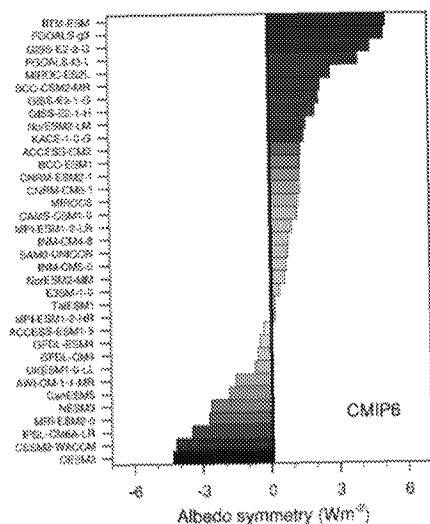


Figure 5.9. Differences in 20-year average reflectivity (albedo) between the Northern and Southern Hemispheres for CMIP6 models used in the most recent IPCC assessment (colored bars). The very small observed difference is indicated by the vertical black line. From Rugenstein and Hakuba (2023).

5.8 U.S. Corn Belt

One of the largest discrepancies between models and observations is in the U.S. Corn Belt, a region of particular importance to global food production. Figure 5.10 shows the warming trends for summertime (June, July, August) for the 12-state Corn Belt (IN, IA, IL, ND, SD, MO, MN, WI, MI, OH, KS, NE) during 1973-2022. All 36 climate models (red) warm far too rapidly compared to observations (blue).

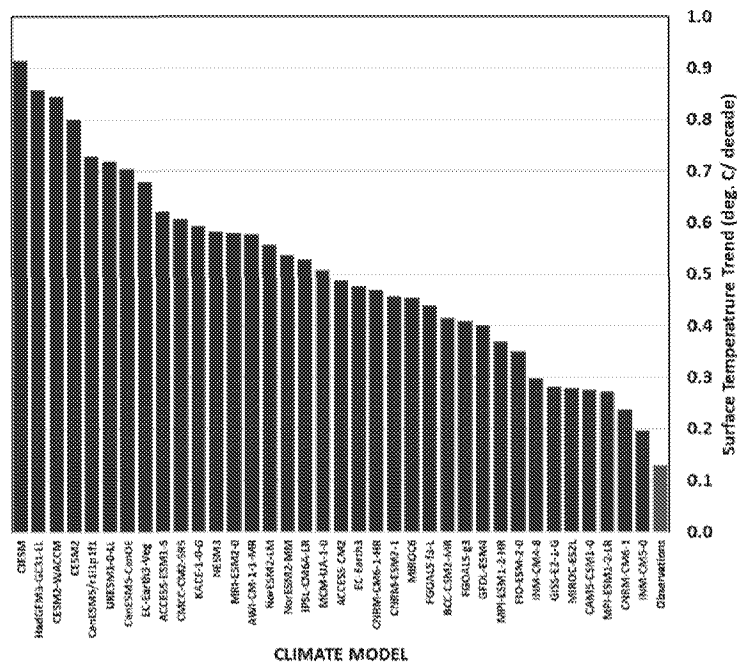


Figure 5.10: Modeled versus observed warming trends in the U.S. Corn Belt, 1973-2022.

As discussed in Chapter 9, the anticipated negative effects of increasing temperatures on U.S. corn yields have not materialized, in contrast to widely publicized studies proclaiming that theoretical future impacts are already being experienced (*e.g.*, Seager *et al.*, 2018).

The IPCC acknowledges limitations in the accuracy of regional climate model outputs. This example shows that users need to assess model projections carefully on a case-by-case basis since local biases may might be sufficiently large that the models are simply not fit for purpose. As has recently been noted by two leaders of the modeling community (emphasis added)

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... for many key applications that require regional climate model output or for assessing large-scale changes from small scale processes, we believe that **the current generation of models is not fit for purpose.** (Palmer and Stevens 2019)

To summarize:

- Climate models show warming biases in many aspects of their reproduction of the past few decades
- They produce too much warming at the surface (except in the models with lowest ECS), too much warming in the lower-and mid-troposphere and too much amplification of warming aloft
- They also produce too much stratospheric cooling, too much snow loss, and too much warming in the US Corn Belt.

- The hemispheric albedo difference in individual climate models ranges widely in sign and magnitude compared to observations. The range in W/m^2 is three times larger than the direct anthropogenic forcing of CO_2 .
- The IPCC has acknowledged some of these issues but not others.

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6 EXTREME WEATHER

Chapter Summary

Most types of extreme weather exhibit no statistically significant long-term trends over the available historical record. While there has been an increase in hot days in the U.S. since the 1950s, a point emphasized by the IPCC-AR6, numbers are still low relative to the 1920s and 1930s. Extreme convective storms, hurricanes, tornadoes, floods and droughts exhibit considerable natural variability, but long-term increases are not detected. Some increases in extreme precipitation events can be detected in some regions over short intervals but the trends do not persist over long periods and at the regional scale. Wildfires are not more common in the U.S. than they were in the 1980s. Burned area increased from the 1960s to the early 2000's, however it is low compared to the estimated natural baseline level. U.S. wildfire activity is strongly affected by forest management practices.

6.1 Introduction

High impact weather extremes, usually related to temperature, precipitation and/or high wind, can disrupt infrastructure and therefore endanger human health and wellbeing. The issue is not whether extremes occur. Rather, it is whether there are long-term (decadal scale) changes in the frequency or character of extremes (“detection”), as well as the extent to which such changes and the attendant changes in hazards are caused by anthropogenic emissions of greenhouse gases (“attribution”; e.g., IPCC-AR6 Seneviratne *et al.* 2021).

It is naïve to assume that any recent extreme event is caused by human influences on the climate. Climate is about the statistical properties of weather over decades, not single events. Further, there are only about 130 years of reliable observational records that can be analyzed statistically. That brief interval does not begin to contain all the extreme events that the climate system can create on its own. Over geologic time the climate system has generated an (essentially) infinite variety of weather patterns and extremes that humans have never observed and thus are absent from the databases used to determine extreme statistics [see *Perils of short data records* below]. For that reason, attributing an extreme event unprecedented in the record requires assumptions about the magnitude of natural variations.

This chapter is concerned with detection of trends in extreme weather, while Chapter 8 considers causal attribution, with Section 8.4 specifically addressing extreme weather. If no trend is detected, then clearly there is no basis for attribution. But even where a trend is observed, attribution to human-caused warming does not necessarily follow.

This is especially true for precipitation events. The hydrological literature has long noted the phenomenon of Long-Term Persistence (LTP) in rainfall data (Hurst 1951, Cohn and Lins 2005, Markonis and Koutsoyiannis 2016). LTP has a formal mathematical definition, but it can be thought of as the presence of natural variations with strong autocorrelations that result in cycle-like behavior on long time scales. The presence of LTP requires long records to accurately estimate variability. Analysis of records that are short relative to the LTP scale will tend to underestimate variability, therefore overstating the significance of apparent trends and underestimating the likelihood of extreme events (Cohn and Lins 2005).

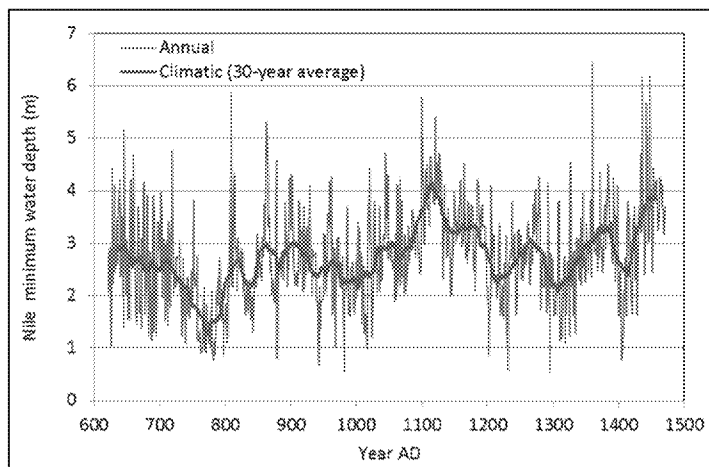


Figure 6.1.1: The annual minimum depth of the Nile River near Cairo over more than 650 years from 622 to 1284 A.D. The data, measured in meters, shows a characteristic pattern of year-to-year fluctuations around longer-term trends. Data from Koutsoyiannis (2013)

A good example of LTP is the eight-century long record of the annual minimum height of the Nile River observed at Roda Island in Cairo shown in Figure 6.1.1. The Nile River is fed by precipitation over a 4 million square mile drainage basin, an area equal to about one third of CONUS. Since human influences on the global climate were negligible before the 20th century, the century-scale variability of the thirty-year average is entirely natural; Egyptians of the seventh and eight centuries would have been incorrect to assume that the worsening drought during that time was the “new normal.”

With these caveats in mind, we examine the evidence for changes in selected weather and climate extremes. A recurring theme is the wide gap between public perceptions and scientific evidence. It has become routine in media coverage, government and private sector discussions, and even in some academic literature to make generalized assertions that extreme weather of all types is getting worse due to GHGs and “climate change.” Yet expert assessments typically have not drawn such sweeping conclusions and instead have emphasized the difficulty both of identifying specific trends and establishing a causal connection with anthropogenic forcing.

In the sections to follow we provide excerpts from various IPCC and NCA assessment reports denoting the sources as follows:

SREX: The IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (2012)

AR6: The IPCC Sixth Assessment Report Working Group 1 (2021).

NCA4: The U.S. Climate Science Special Report of the Fourth National Climate Assessment (2017) Volume I.

NCA5: The U.S. Climate Science Special Report of the Fifth National Climate Assessment (2023) Volume I.

In the excerpts, *italics* are in the original whereas **boldface** emphasis has been added.

Additionally we present updated data series from standard government sources to provide up-to-date information through 2024 wherever possible.

6.2 Hurricanes and tropical cyclones

The AR6 provides the following assessment of tropical cyclones (TCs; used here as a synonym for hurricanes):

AR6: There is *low confidence* in most reported long-term (multidecadal to centennial) trends in TC frequency or intensity-based metrics due to changes in the technology used to collect the best-track data. (IPCC, 2021 p. 1585)

AR6: It is *likely* that the global proportion of major (Category 3–5) tropical cyclone occurrence has increased over the last four decades . . . There is *low confidence* in long-term (multi-decadal to centennial) trends in the frequency of all-category tropical cyclones. (IPCC, 2023 SPM p. 9)

AR6: A subset of the best-track data corresponding to hurricanes that have directly impacted the United States since 1900 is considered to be reliable, and shows **no trend in the frequency of U.S. landfall events**. (IPCC 2021 p. 1585)

Since 1980, when satellite observations first fully covered the global oceans, we have confidence in the numbers of total global hurricanes and major hurricanes (Category 3 and higher). Figure 6.2.1 shows that on average, each year there are about 50 hurricanes, with about 25 reaching major hurricane status (Maue, 2025). There is substantial year-to-year and decadal variability, a weak decrease in the number of hurricanes, and a slight but insignificant increase in the number of major hurricanes. These two trends combine to create an overall increase in the proportion of major hurricanes.

Global hurricane statistics are dominated by the Northwest Pacific Ocean, which accounts for ~35 percent of total global hurricanes, whereas the Atlantic accounts for ~15 percent of global hurricanes (Colorado State University, 2025). Data in the Atlantic basin extends further back than in the other ocean basins and is most relevant to U.S. policy makers.

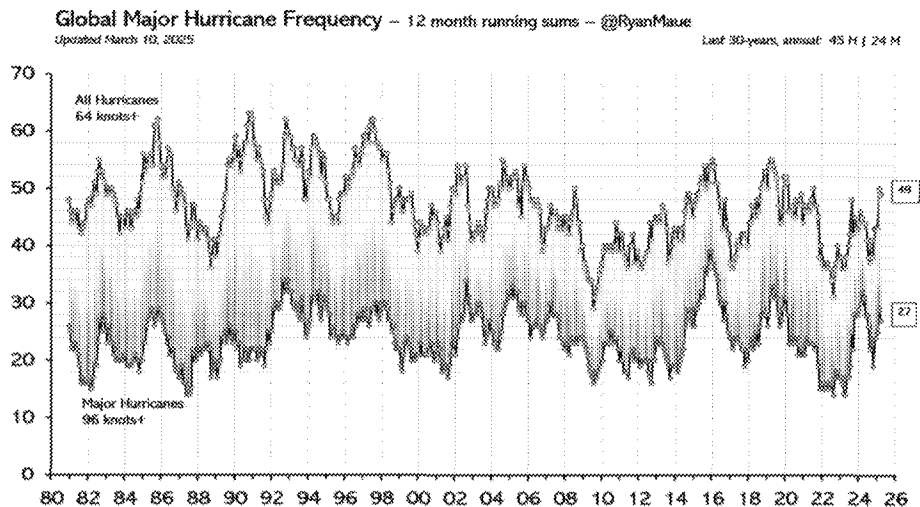


Figure 6.2.1: Global frequency of hurricanes and major hurricanes since 1980.

Figure 6.2.2 shows the frequency of Atlantic hurricanes and major hurricanes (Category 3 and higher) back to 1920. Data prior to 1965 (the onset of satellite observations in the Atlantic, shaded in blue) shows some undercounting, with data prior to 1920 showing substantial undercounting (Vecchi and Knutson, 2011). All measures of Atlantic hurricane activity show a significant increase since 1970. However, the period from 1971-1994 saw exceptionally low activity, with high activity (comparable to the past two decades, even with undercounting) also observed during the 1950's and 1960's, and even in the 1930's.

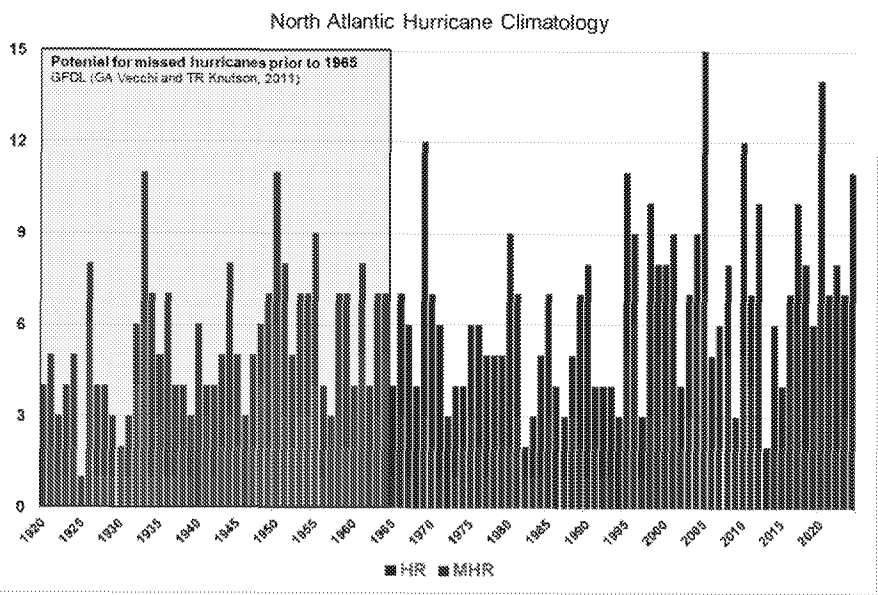


Figure 6.2.2: Atlantic frequency of hurricanes(HR) and major hurricanes(MHR) since 1920. Source National Hurricane Center (2024)

Figure 6.2.2 shows that Atlantic hurricanes vary strongly on decadal and multidecadal time scales. These variations are associated primarily with the Atlantic Multidecadal Oscillation (AMO), which is manifest in basin-wide sea surface temperature and sea level pressure fluctuations connected to large scale ocean circulation patterns. The AMO was in its warm phase during 1926-1970 and 1995-present, but in its cool phase during 1971-1994. It has its greatest impact on the number of major hurricanes (Category 3+), identified by Goldenberg *et al.* (2001) as associated with above normal SST s and decreased vertical shear in the AMO warm phase (see also Bell and Chelliah, 2006; Klotzbach *et al.*, 2018).

Klotzbach *et al.* (2018) conducted a comprehensive evaluation of the landfalling hurricane data for the Continental U.S. since 1900. Figure 6.2.3 updates their analysis through 2024. While the largest numbers of landfalling hurricanes are from 2004, 2005 and 2020, there is no statistically significant trend since 1920. Figure 6.2.3 also shows the time series for major hurricane landfalls (Category 3-5). The largest year in the record is 2005, with 4 major hurricane landfalls. However, following 2005 there were no major hurricanes striking the U.S through 2016, the longest such period since 1920.

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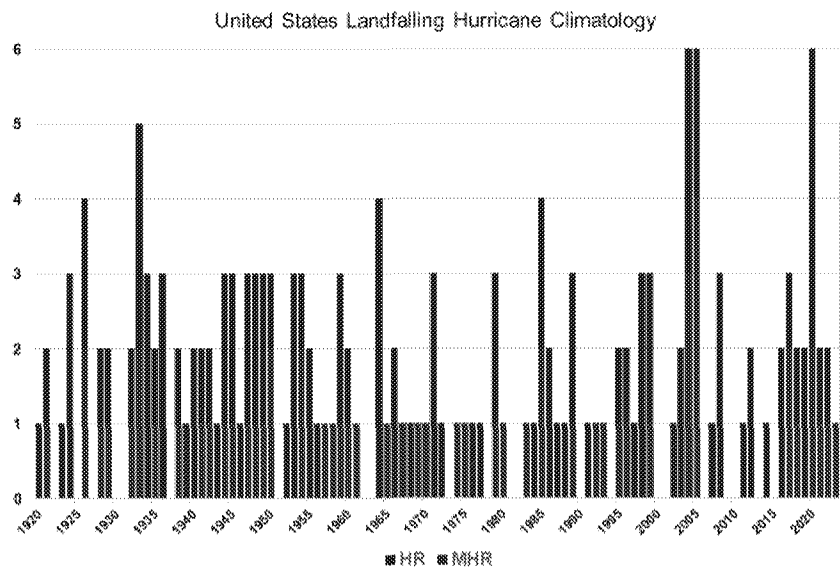


Figure 6.2.3: U.S. landfalling frequency of hurricanes (HR) and major hurricanes (MHR) since 1920. Source NOAA HRD(a) (2024)

Figure 6.2.3 shows substantial interannual to multidecadal variability in U.S. landfall activity. Klotzbach *et al.* (2018) examined how the landfall counts vary with ENSO (El Niño versus La Niña) and the warm versus cold phases of the Atlantic Multidecadal Oscillation (AMO).

Villarini *et al.* (2012) provide an analysis of U.S. hurricane landfalls back to 1878. While it is possible that some landfalls were missed in the late 19th century owing to sparsely populated regions on the Gulf Coast, it is remarkable that the highest year in the entire record is 1886, with 7 hurricane landfalls, when human influences on the climate were much smaller than they are today.

Table 6.2.1 shows the 10 strongest hurricanes (plus ties) to make U.S. landfall. Of the hurricanes that have made landfall with sustained winds greater than 150 mph, only one has occurred in the 21st century.

In summary, analyses of both global and regional variability and trends of hurricane activity provide the basis for detecting changes and understanding their causes. The relatively short historical record of hurricane activity, and the even shorter record from the satellite era, is not sufficient to assess whether recent hurricane activity is unusual relative to the background natural variability. Atlantic hurricane processes are influenced substantially by the natural modes of ocean circulation variability in the Atlantic, notably the Atlantic Multidecadal Oscillation. While it has long been hypothesized that a rising global sea surface temperature would cause an increase in hurricane intensity, identification of any significant trend in the hurricane data is hampered by a short data record and substantial natural variability.

Rank	Year	Landfall Wind (MPH)	Name
1	1935	185	"Labor Day"
2	1969	175	Camille
3	1992	165	Andrew
4	2018	160	Michael
5	1856	150	"Last Island"
5	1886	150	"Indianola"
5	1919	150	-----
5	1932	150	"Freeport"
5	2004	150	Charley
5	2020	150	Laura
5	2021	150	Ida
5	2022	150	Ian

Table 6.2.1 Strongest hurricanes to make landfall along the U.S. coast. Source (NOAA HRD(b), 2024)

6.3 Temperature extremes

The AR6 assessment focused on the period after 1950 and reported increasing trends in heatwave frequency and intensity. However, the NCA4 noted that heatwave activity in the U.S. reached a peak in the 1930s (Figure 6.3.1).

AR6: It is *virtually certain* that hot extremes (including heatwaves) have become more frequent and more intense across most land regions since the 1950s, while cold extremes (including cold waves) have become less frequent and less severe (SPM, A3.1)

AR6: In North America, there is very robust evidence for a *very likely* increase in the intensity and frequency of hot extremes and decrease in the intensity and frequency of cold extremes for the whole continent, though there are substantial spatial and seasonal variations in the trends. Minimum temperatures display warming consistently across the continent, while there are more contrasting trends in the annual maximum daily temperatures in parts of the USA. (Chapter 11, p 1550)

NCA4: Changes in warm extremes are more nuanced than changes in cold extremes. For instance, the warmest daily temperature of the year **increased** in some parts of the West over the past century, but there were **decreases** in almost all locations east of the Rocky Mountains. In fact, all eastern regions experienced a net **decrease**, most notably the Midwest (about 2.2°F [1.2°C]) and the Southeast (roughly 1.5°F [0.8°C]). (pp. 190-191)

NCA4: Since the mid-1960s, there has been only a very slight increase in the warmest daily temperature of the year (amidst large interannual variability). Heat waves (6-day periods with a maximum temperature above the 90th percentile for 1961–1990) increased in frequency until the mid-1930s, became considerably less common through the mid-1960s, and increased in frequency again thereafter. As with warm daily temperatures, **heat wave magnitude reached a maximum in the 1930s.** (pp. 190-191)

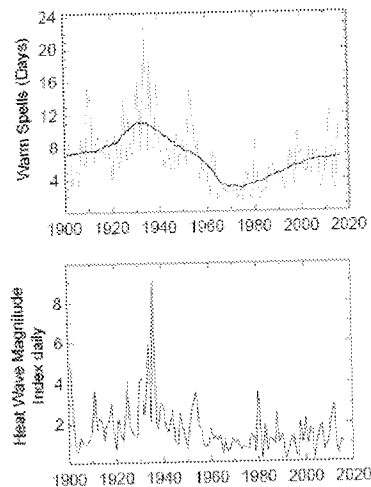


Figure 6.3.1: U.S. Heat waves since 1900. Source: NCA4 Figure 6.4

6.3.1 Temperatures in the U.S. are becoming less extreme

Daily maximum temperatures in the warm season (T max, May-Sep) and daily minimum temperatures in the cold season (T min, Dec-Mar) are available beginning in Dec 1898 (126 years). The dataset consists of 1,211 CONUS stations designated as United States Historical Climate Network or USHCN stations (see Figure 6.3.2; Quinlan *et al.* 1987, Karl *et al.* 1990). These stations were selected by NOAA as having the fewest problematic issues with gaps, station moves, and instrument changes. Where gaps still exist, nearby stations (bias-corrected) were merged so that the median volume of data available for a station is 98%. Although there are certainly errors in the dataset, including unresolved spurious warming due to UHI effects that especially bias T min records, this data set is sufficiently accurate for assessing trends in T max heat extremes.

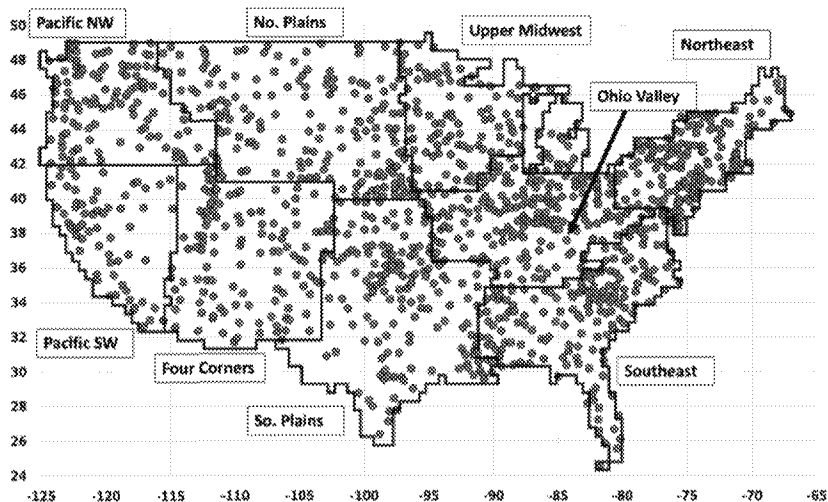


Figure 6.3.2 Locations of USHCN temperature stations. Source: USHCN.

We begin with the question of whether the occurrence of daily record high or low temperatures has changed since Dec 1898. Each warm-season has 153 days (1 May to 30 Sep) and each cold-season has 122 days (1 Dec to 31 Mar). For each station and day, we calculated the year in which the record highest (lowest) temperature occurred. With 126 years of observations, if there were no temperature trends over time, the expected number of records for Tmax would be 1.21 ($=153/126$) per station per year and for Tmin 0.96 ($=122/126$) per station per year.

Figure 6.3.3 shows the observed distribution in time of the occurrence of these extreme events. There is a common feature in many metrics of warm-season extremes in the CONUS - the exceptional heat of the 1920s and especially the 1930s, peaking in 1936. On a per-station average, 60 percent of the Tmax records and 59 percent of the Tmin records occurred in the first half of the period (1899-1961).

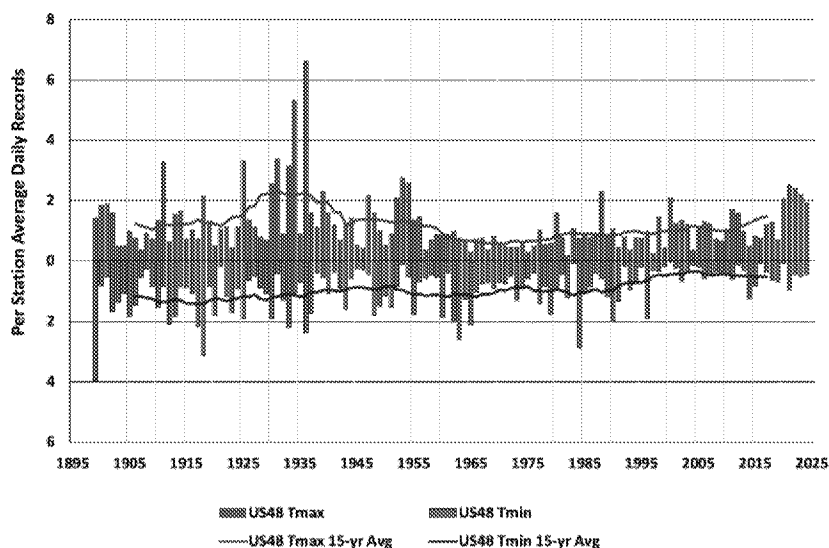


Figure 6.3.3 Number of daily record High (red) and Low (blue) temperatures for warm and cold seasons in the CONUS. The lines represent the 15-year running, centered average. Source: 1,211 USHCN stations supplemented as needed to achieve a minimum of 92 percent of observations in the 126-year period since Dec 1898. US48: contiguous U.S. states. Tmax: maximum temperature. Tmin: minimum temperature.

On the cold side, the Valentine's Day Arctic outbreak in Feb 1899 stands as the most extensive cold extreme experienced by CONUS, with 1917 in 2nd place. The frequency of cold records has declined, especially over the last quarter of the period in which only 13 percent of the extreme cold events were measured. In contrast, 25 percent of the extreme Tmax records were achieved in the last quarter, in accordance with statistical expectations. These general features have been noted in past assessments (see above, IPCC AR6, NCA4). Combining the two records histories, the overall reduction in numbers of both cold and hot extremes over the past century indicates a climate less prone to extremes.

This pattern is also shown in Figure 6.3.4. For each station and for each year the hottest warm season and coldest cold-season temperatures were calculated. Then the differences between these were computed by station and geographically-averaged over all stations, thus yielding an annual measure of the expected range of local extreme temperatures for each year. Figure 6.3.4 shows the 15-year trailing average of this measure, which has clearly declined over the past century.

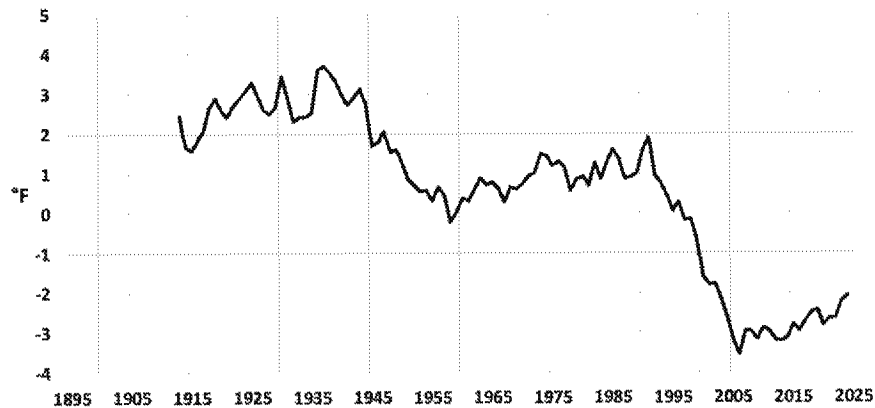


Figure 6.3.4. 15-year trailing average of the difference each year of each station's hottest warm-season Tmax and coldest cold-season Tmin relative to the long-term average. Source: Author analysis of USHCN data.

The average difference for each station between the hottest summer Tmax and coldest winter Tmin has declined by about 5°F in the past 126 years. The decline is due mostly to warmer winter Tmin, but a decline in summer Tmax is also a factor. The rise in Tmin has been strongly related to the growing presence of manufactured surfaces around the weather stations over the last 100+ years (the so-called urban heat island effect; [Section 3.3](#) and [Spencer et al. 2025](#)).

In summary, while temperature extremes are regularly experienced in the U.S. and attract a great deal of media attention, long term records show the U.S. climate has become less extreme over time (milder) when measured by the range between warm season maxima and cold season minima.

6.3.2 Exceedances of a heat threshold

Under the heading of “The Risk of Temperature Extremes is Changing”, the most recent U.S. National Climate Assessment report (NCA5) notes the increase in a threshold metric of number of days at or above 95°F, stating,

The western U.S. has been particularly affected by extreme heat since the 1980s ..., experiencing a larger increase in days over 95°F, as would be expected given the greater warming in that region relative to the eastern US. Several major heatwaves have affected the U.S. since 2018, including a record-shattering event in the Pacific Northwest in 2021.

Are the occurrences of 95°F days changing? In a climate as varied as that of CONUS, threshold statistics can be misleading. A region with many stations that have near 95°F Tmax average temperatures in the summer might see large swings in the metric when only small changes in average temperature occur. Elsewhere with stations that either rarely or virtually always achieve 95°F Tmax temperatures, a small change will not have much impact on the results.

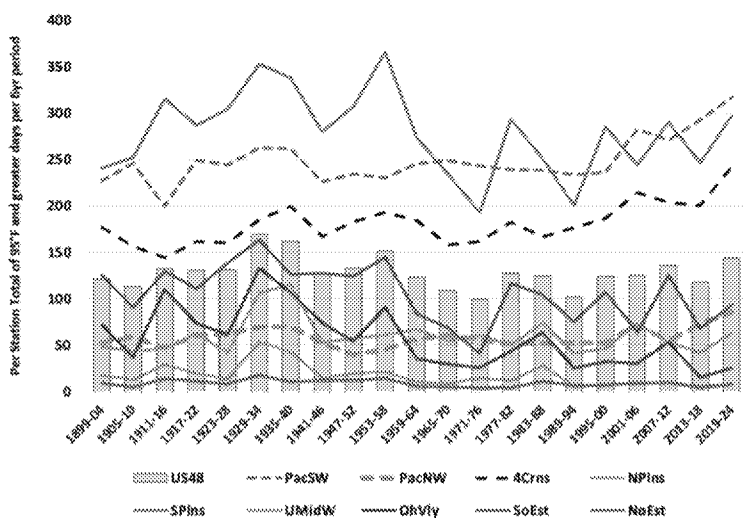


Figure 6.3.5. Total number of days $\geq 95^{\circ}\text{F}$ in 6-yr periods, U.S. 48 (bars) and regions (lines). A 6-year period is used as this evenly divides the 126-year record. US48: contiguous U.S. states. See Figure 6.3.2 for region names. Source: Author analysis of USHCN data.

In the past 126 years, the average CONUS station experienced 129 days exceeding 95°C per 6-yr period, but the regional values range from 278 in the Southern Plains to 9 in the Northeast. Thus, such threshold analyses must be interpreted with caution. Figure 6.3.5 shows that only three of the nine regions, all in the West, have experienced upward trends in the number of 95°F or hotter days (dashed lines). The CONUS as a whole has not, and the other six regions have experienced declines.

The Pacific NW heatwave of 2021 referenced in the NCA5 quote will be examined more closely in Section 8.6.1. The evidence indicates that it was a single, unprecedented event in the record, not part of a pattern of increasing extreme heat. For example, the 5-day average tropospheric grid-point temperature anomaly over the Pacific NW during that event was $+10.8^{\circ}\text{C}$, the most extreme Northern Hemisphere grid point summer anomaly in the 46 years from over 4 million grid values. In contrast, the global temperature anomaly during that time was virtually zero ($+0.03^{\circ}\text{C}$, Mass *et al.* 2024).

The NCA5 heading “The Risk of Temperature Extremes is Changing” suggests pervasive positive trends are now being observed in threshold temperatures, but that is not evident in the figures above.

6.3.3 Heatwaves

Heatwaves (consecutive days that exceed an extreme threshold) have a greater societal impact than a single daily record temperature. We measure “Heatwave Days” here as the count of all days in May-Sep each year that exceed the 90th percentile for that day and that lie within a period of at least six consecutive days. This is equivalent to the method used in NCA4, except that the reference period here is the entire record 1899-2024 while NCA4 truncated the reference period to 1961-1990, which was a cool period. That truncation boosts positive results (days exceeding the 90th percentile) in periods warmer than the reference period, especially starting in 1960 and moving to the present (see Figure 6.3.7 SHOULD IT BE 6.3.6?? and discussion below).

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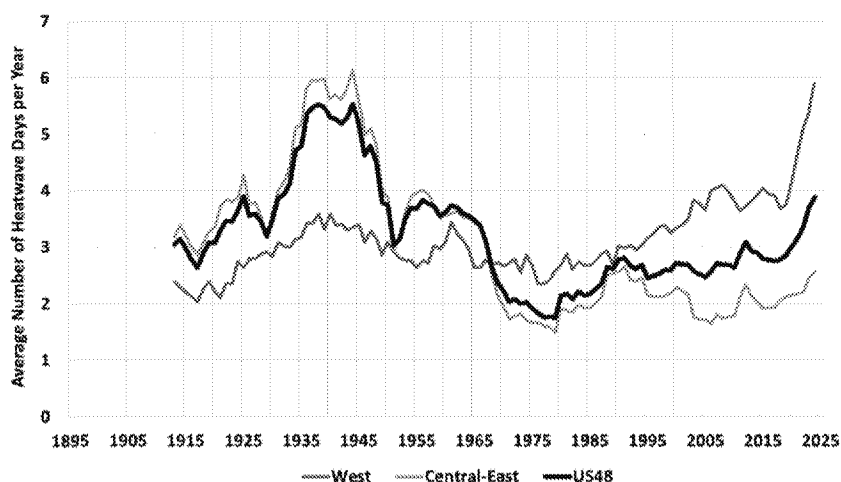


Figure 6.3.6 15-year trailing average of number of heatwave days per year per station in the CONUS (blackline) and two regions: West (red), Central-east (green).

Figure 6.3.6 indicates that there are regional variations in heatwave activity. The excessive heat of the first half of the 20th century occurred primarily in the eastern two-thirds of the nation, while the West has seen a recent increase of heatwave days (NCA5). This indicates that the background warm season circulation favored heatwaves in the eastern portions of the country in the first half of the 20th century, but in the 21st century the patterns have favored heatwaves in the West. For CONUS as a whole, heatwaves are no more common today than they were a century ago, consistent with the upper panel of our Figure 6.4.1 taken from NCA4.

This metric varies significantly with region. The four northern regions (Pacific NW, Northern Plains, Upper Midwest, and Northeast) on average experience 15 to 27 heatwave days per 15-year period. In contrast, the five southern regions (Pacific Southwest, 4-Corners, Southern Plains, Ohio Valley and Southeast) see 37 to 54 such days, essentially twice as many. This suggests the summer circulation pattern is more prone to stationary events in the southern regions while transient systems in the northern regions are more common and thus cut short these potentially longer events.

The analysis of heatwaves is an example of why it is important to consider complete datasets and appropriate metrics. The NCA5 directs readers to the website [[HYPERLINK "https://www.globalchange.gov/indicators/heat-waves"](https://www.globalchange.gov/indicators/heat-waves)] (USGCRP 2023) to view a figure showing the number of urban heatwaves by decade from the 1960s, which we reproduce as Figure 6.3.7.

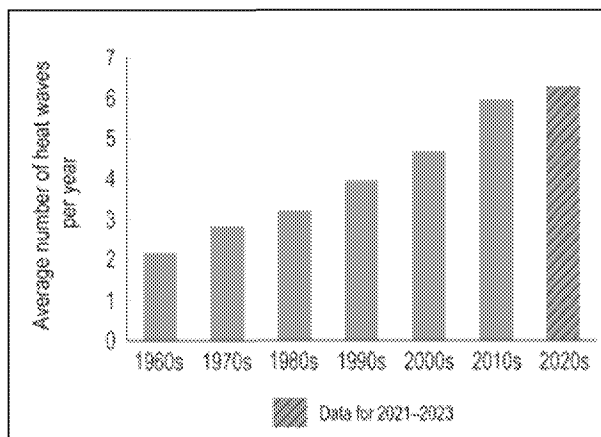


Figure 6.3.7: Average number of urban heatwaves per year for 50 large U.S. metropolitan areas, a misleading metric for reasons explained in the text. From [HYPERLINK "https://www.globalchange.gov/indicators/heat-waves"], [LINK BROKEN](#)

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The figure shows a monotonic increase in each decade from two occurrences per year in the 1960s to six in the 2020s. The definition of a heatwave used is an unusual but practical measure of human discomfort - a period of at least 2 consecutive days when the *minimum* apparent temperature (combination of temperature and humidity) exceeds the 85th percentile. Note too, the dataset is limited to the 50 largest U.S. cities.

Given the unusual heatwave definition and urban focus, these increasing values since 1960 presented in USGCRP (2023) are not informative about long term trends or the influence of GHG emissions for at least two reasons. First, as shown in Figures 6.3.1 and 6.3.6, the 1960s was the coldest decade and 1970s the second coldest decade since the 1910's, so this starting date preconditions the time series to show increases. Second, post-1960 urbanization in these cities is a major factor in the rise of T_{min} relative to co-located T_{max} and relative to T_{min} at nearby rural stations. This does not dismiss the real rise in nighttime temperatures in major U. S. cities and the societal impacts associated with these changes. However, we note for a variety of reasons, that summer T_{max} (especially in rural areas) is a better metric for detecting changes in heatwaves influenced by changes in the background climate due, for example, to increasing GHGs (Christy *et al.* 2009). For the CONUS as a whole, the evidence in this section suggests GHG emissions have had little-to-no effect on heatwaves against the background of urbanization and natural climate variability.

6.4 Extreme precipitation

The IPCC-AR6 assessed that an increase in heavy precipitation has been observed in data starting in the 1950s.

AR6: The frequency and intensity of **heavy precipitation events have increased** since the 1950s over most land area for which observational data are sufficient for trend analysis (high confidence). (SPM A3.2)

AR6: In North America, there is robust evidence that the **magnitude and intensity of extreme precipitation has very likely increased** since the 1950s. Both [one-day maxima] and [5-day maxima] have significantly increased in North America during 1950-2018. (Chapter 11, p. 1560)

The U.S. National Climate Assessments (NCA4, NCA5) have highlighted an increase in the occurrence of the heaviest precipitation events (defined in different ways) primarily in the eastern half of the CONUS, especially the Northeast, when starting the analysis in either 1901 or 1958. Interestingly, the regional variations indicate that the largest increases in extreme precipitation events are in the Northeast and the smallest in the West, a pattern counter to the changes in temperature extremes (Figure 6.3.6).

McKittrick and Christy (2019) examined long-term and consistent station observations of extreme daily precipitation to test some of these NCA claims for the Southeast and West Coast using a trend model with a non-parametric variance estimator robust to the complex autocorrelation properties of precipitation data. When the time series were extended back in time (as far as 1872 in some cases) or ~~when starting started~~ later (1978), there were no significant trends for either region.

These findings have been updated for this report (McKittrick and Christy 2025) with similarly constructed observations from 29 stations on the CONUS Pacific Coast (1893ff from San Diego CA to Blaine WA) and 24 stations in the humid Southeast (1872ff from Austin TX to Washington DC), also adding 27 stations in the Northeast (1888ff from Buffalo NY to Eastport ME). The locations are shown in Figure 6.4.1. The stations were selected based on availability of long-term high-quality records. The regions are each associated with important features of extreme precipitation behavior: the Pacific coast is associated with landfalling atmospheric rivers for which AR6 cites evidence of increasing activity since 1948 with further increases expected as the world warms (AR6 8.3.2.8.2); the NCA report indicates that the Northeast has experienced the greatest increase in extreme events, and the Southeast is also a place noted in the NCAs as having increased extreme events.

The results of applying the analysis of McKittrick and Christy (2019) were as follows for each region, then followed by further explanation.

Pacific Coast heavy rainfall events

- The average precipitation trend is statistically significant (downwards) in Astoria OR; insignificant elsewhere.
- The trend in rainfall variance is positive and significant in Big Sur CA; insignificant elsewhere.
- The trend in daily maximum precipitation is positive and significant in Aberdeen WA and Big Sur CA and negative and significant in Newport OR (insignificant elsewhere).
- Averaged over all stations in the region, none of these three trend parameters is statistically significant.

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The Pacific Coast receives considerable precipitation from Atmospheric River (AR) events which often last more than a day or two (e.g., Gershunov *et al.* 2017, Pan *et al.* 2024). The worst series of such events in recent history was the so-called ARkStorm that occurred between December 1861 and January 1862; it dumped nearly 10 feet of rain in parts of California and submerged the entire Central Valley for weeks under as much as 15 feet of water (Brewer 1930, Null and Hulbert 2007). Additionally, Paleoclimate research has found six megastorms more severe than 1861–1862 in California during the last 1800 years, occurring at intervals of 300 years or so (Porter *et al.* 2011).

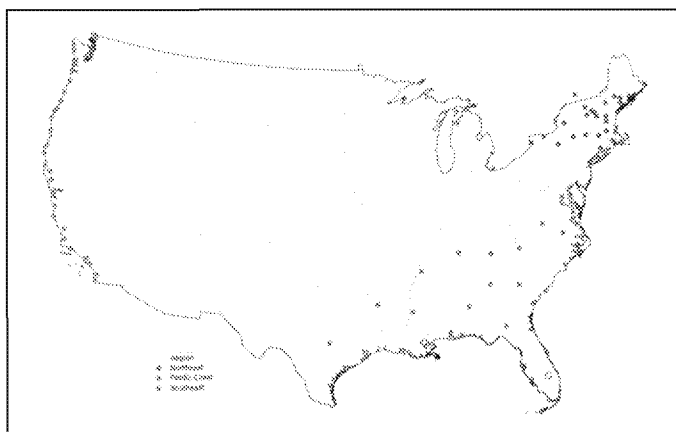


Figure 6.4.1: Locations of precipitation monitoring stations used in this report. Orange: Pacific coast. Blue: Northeast. Green: Southeast. Data from McKittrick and Christy (2025).

We examine occurrences of 5-day deluges as follows. Taking the Pacific coast as an example, a 130-year span contains 26 5-year intervals. At each location we computed the 5-day precipitation totals throughout the year and selected the 26 highest values across the sample. A single year ~~may-might~~ have more than one of the 26 heaviest. Each of those can be thought of as 1-in-5yr events. If there are no trends in precipitation, then the total number of these events across all stations should be evenly ~~spread-out~~ spread over the years. In Fig. 6.4.2 we show the distribution in time of these events for the Pacific coast. The deluges associated with the massive 1997-98 El Niño event are readily apparent. While erratic, as is typical of such precipitation metrics, there is no indication of a tendency to become more frequent over time.

Southeast heavy rainfall events

- The trend in average precipitation is positive and statistically significant in Mobile AL and Quitman GA but insignificant elsewhere.
- The trend in rainfall variance is positive and significant in Mobile AL but insignificant elsewhere.
- The trend in daily maximum precipitation is positive and significant in Vicksburg MS and Norfolk VA but insignificant elsewhere.
- Averaged over all stations in the region none of these three trend parameters is statistically significant

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Figure 6.4.3 shows the same calculation is analogous to Figure 6.4.2 for the last 150 years in the Southeast humid zone. The temporal pattern of 5-day totals of the 1-in-5yr heavy events is generally unremarkable, though a cluster of higher values appears in 1995 to 2019. The increase in those years is due largely to the 4 northeastern-most stations of Wilmington NC, Weldon NC, Washington DC, and Norfolk VA. This confirms the pattern indicated in NCA4 and NCA5 -- an increasing frequency of heavy events due to a temporal clustering of tropical storms from eastern NC to Maine discussed below. Otherwise, the remaining 20 stations show an unremarkable temporal distribution of heavy events.

BOX: Perils of short data records

San Francisco provides a good case study of the limitation of using short historical samples to characterize natural variability of extreme events. Suppose we use a 130-year sample of daily San Francisco precipitation from 1895 to 2024 and we look for 3-day, 5-day, 14-day and 30-day rainfall records. The results are as shown in Table 7.2.

Event	Record (inches)	Year
3-day	6.94	2023
5-day	8.55	2023
14-day	12.62	2023
30-day	18.93	1998

Table 6.2: Extreme rainfall records, San Francisco, 1895-2024.

The records all cluster in the more recent years. 2023 appears to be an exceptional year and since it is near the end of the sample, it might suggest that the climate has shifted into a more hazardous state, perhaps because of human influences. [Notes: “2023” indicates the event occurred in the water-year of Aug 2022 to Jul 2023.]

But the picture is very different if we use a sample that begins 45 years earlier, in 1850. Table 6.3 shows that the record-setting events all happened in the 1860s. Furthermore 2023 is now not even in 2nd place but falls to 3rd or 4th place. And comparing the records of the two charts shows the extreme precipitation events in 1862 and 1867 involved considerably more rainfall than the 1998 and 2023 events, with 14- and 30-day totals about 50 percent higher.

Event	Record (inches)	Year	Rank of 130-yr extreme listed in Table 6.2
3-day	8.85	1867	3
5-day	9.80	1867	3
14-day	19.05	1862	4
30-day	28.25	1862	2

Table 6.3: Extreme rainfall records, San Francisco, 1850-2024.

The range of natural variability is made even more remarkable when paleoclimate evidence is examined. Porter *et al.* (2011) discovered that in the past 1,800 years at least six megastorms were more intense than the devastating 1861-62 ARKStorm that struck the region. Evidently such extreme events, “unprecedented” in our 1895-2024 sample, have impacted the region about every 300 years, though not since 1895.

This example illustrates the limitations of using relatively short climate periods (~130 years) to assess the character and range of natural variability in general and of extreme events in particular. Accurate representation of the full range of natural variability is necessary for any attribution analyses (see [Section 8.6](#)). Infrastructure planners, emergency management institutions and attribution scientists would understand the significant mischaracterization of the magnitude of a future extreme if based only on the last 130 years. In this case, a single time-sample of 130 years provides an underestimation of the extreme value by up to 50 percent determined when adding only 45 more years of observations. Compared to millennial-scale paleoclimate evidence, an even greater underestimation would occur. An important lesson is that the climate can deliver great surprises on its own, even without human influences.

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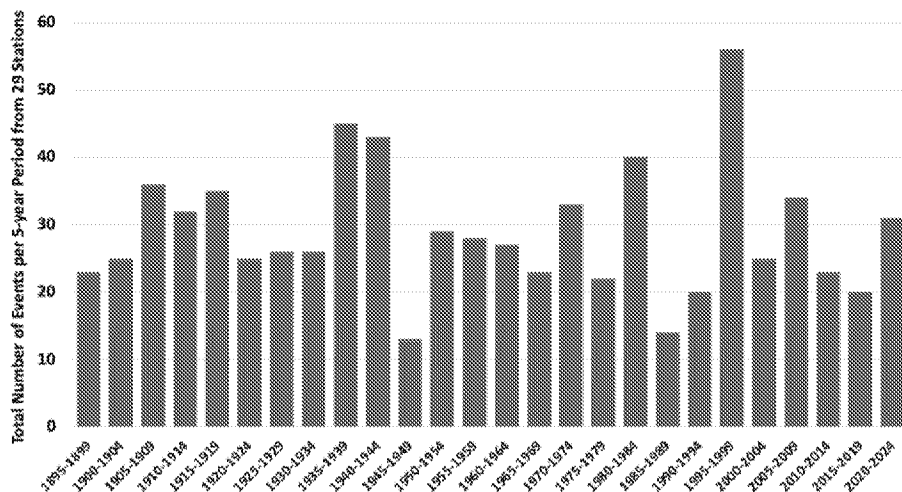


Figure 6.4.2. The time distribution by 5-year periods of the 26 heaviest (1-in-5 yr) occurrences for 29 stations on the Pacific coast.

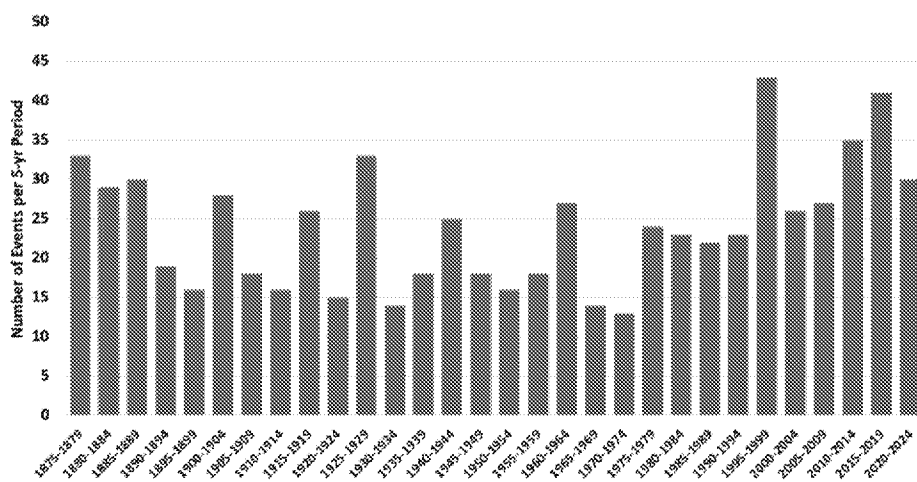


Figure 6.4.3. As in Fig. 6.4.2 but for the heaviest 30 (1-in-5yr) events for 24 stations in the humid Southeast from Austin TX to Washington DC in 5-year bins for 1875-2024.

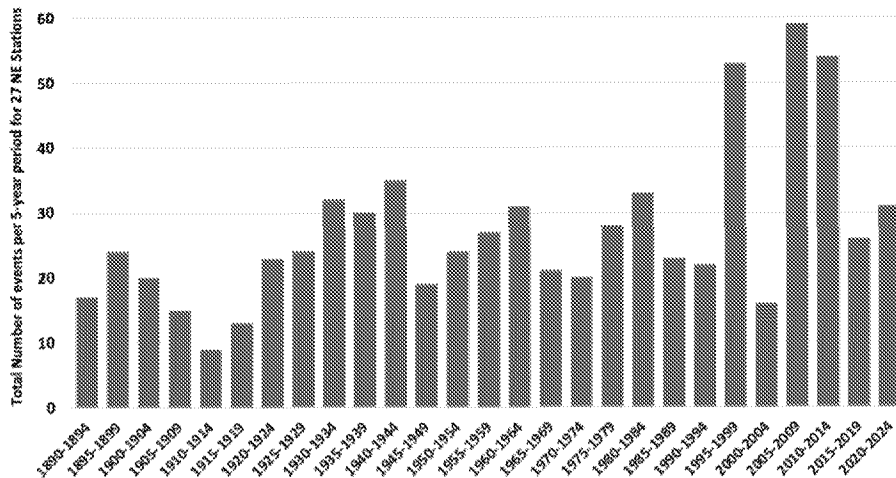


Figure 6.4.4. As in Fig. 6.4.2 but for the heaviest 27 (1-in-5yr) 3-day precipitation events for 27 Northeast stations from NY to ME, including Montreal.

Northeast heavy rainfall events

- The trend in average precipitation is positive and statistically significant in 12 of 27 locations and also in the regional average.
- The trend in rainfall variance is positive and significant in Portland ME, Albany NY, Buffalo NY and Eastport ME but insignificant elsewhere.
- The trend in daily maximum precipitation is positive and significant in Portland ME, Gardiner ME and Eastport ME but insignificant elsewhere.
- When averaged over all stations in the region, there is no statistically significant trend in either the precipitation variance or maximum

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Fig. 6.4.4 shows the same calculation is analogous to Figure 6.4.2 for the last 135 years in 27 stations in the Northeast (including Montreal Canada). We use 3-day totals here as this produced the largest temporal variations in time. In this region, 77 percent of events occur during June to October and are dominated by incursions of hurricanes, tropical storms, or tropical storms that transition to extratropical systems. According to NCA4 and NCA5 this region experienced the largest increases in extreme events, so it merits a closer examination.

There is a noticeable clustering of extreme events from 1995 to 2014. Howarth *et al.* (2019) examined a similar region as in Fig. 6.4.4.5 that includes PA and NJ and reported significant differences in various precipitation extremes between two 18-year periods, 1979-96 and 1997-2014. That included a 317 percent increase in 24-hr events exceeding 6 inches, while we find a 58 percent increase over the same years. However, Figure 6.4.4.5.5 shows that frequency drops sharply after 2014, returning to the long-term average

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in the subsequent 5-year intervals, again illustrating the perils of drawing conclusions from short-term trends in highly variable metrics.

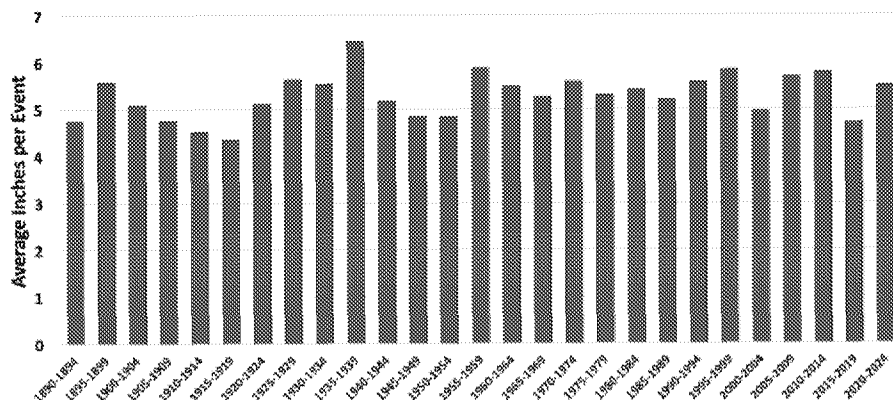


Figure 6.4.5. Average amount of precipitation falling in the 1-in-5yr events for the NE stations.

The high percentage increase in the Howarth *et al.* sample is associated with small numbers at relatively few locations: there were only 6 in the first period and 25 in the second across 58 stations. Most of the stations did not record such an event. If there is a region-wide increase in heavy events, it should be seen in the average across all stations. Figure 6.4.5 shows the average precipitation in the 1-in-5 yr events across the NE. The trend is only +0.04 inches/decade. The highest amount, 1935-39, includes the Great New England Hurricane of 1938, one of the rare major (Category 3 or higher) hurricanes to strike the region. The results in Figs. 6.4.4 and 6.4.5 thus suggest that though there was a surge in the number of events at a few locations during the 1995 to 2014 interval, there was no regional pattern and the change did not persist beyond 2014.

Jong *et al.* (2024) document the increase of tropical influences on precipitation events in the Northeast since 1959 and concluded, “The autumn extreme precipitation trend over the Northeast U.S. is primarily attributed to tropical cyclone-related events since the 1990s.” The question then becomes: “Was the temporal clustering of tropical systems in 1997-2014 which affected the Northeast a response to increasing GHGs?” Jong *et al.* examined CMIP-6 model output which suggests that there will be fewer such systems in the 21st century but that the intensity of the rainfall events might increase. This conjecture is not seen in Fig. 6.4.5 where the amount-per-event has remained steady over the 135-year period.

There is some evidence to indicate the heaviest rainfall events may be redistributed due to the impact of urban infrastructure on the local weather (e.g., Pielke Sr. *et al.* 2011, Zhang *et al.* 2018, Yang *et al.* 2024). Yang *et al.* state “Cities that experience compact development tend to witness larger increases in extreme rainfall frequency over downtown than their rural surroundings, while the anomalies in extreme rainfall frequency diminish for cities with dispersed development.” While this is an important insight to consider, the effect on the specific stations used in this analysis is unknown, or at least not detectable in Fig. 6.4.5.

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INDENT In summary, some U.S. regions show short-duration increases in extreme precipitation events, consistent with natural variability. But analysis of long term, nationwide historical records that considers the autocorrelation properties of precipitation data does not support the claim that extreme short-duration rainfall events are becoming more frequent or intense.

6.5 Tornadoes

The IPCC AR6 assesses tornado trends in the U.S. as follows:

[O]bservational trends in tornadoes, hail, and lightning associated with severe convective storms are not robustly detected due to insufficient coverage of the long-term observations. There is *medium confidence* that the mean annual number of tornadoes in the USA has remained relatively constant. (Chapter 11, section 11.7.3, p. 1594)

The monitoring of weak tornadoes has changed over time. The growth of rural populations and the increasing ability to take video with hand-held devices has led to more frequent reports of weak tornadoes that produce minimal damage. In contrast, strong to violent tornadoes have been observed more consistently over time. Note that tornado strength is measured by the damage it produces, not by the visual appearance of the funnel. Limited real-time observational capabilities in earlier decades did not prevent identification because strong to violent tornadoes leave much more damage which will be assessed later even if the tornado itself was not observed. Since statistics began in 1950, there has been a substantial decrease (by about 50%) in the number of strong to violent tornadoes as shown in Fig. 6.5.1a.

To summarize, there is a noticeable downward trend in the number of severe tornadoes in the U.S. since 1950. After 1990 the number of weak tornadoes in the U.S. has remained roughly constant; data before that are incomplete due to limited monitoring.

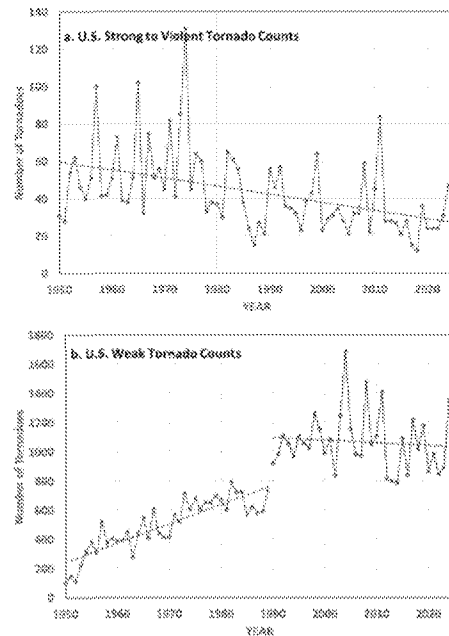


Figure 6.5.1. Annual U.S. tornado counts for (a) strong to violent tornadoes (EF3 to EF5), and (b) weak tornadoes (EF0 to EF2). Based upon NOAA Storms Prediction Center data, available at https://www.spc.noaa.gov/wcm/data/1950-2024_actual_tornadoes.csv

6.6 Flooding

Changes in floods were assessed as follows:

AR6: The SREX **assessed low confidence for observed changes in the magnitude or frequency of floods** at the global scale. This assessment was confirmed by the AR5 report. The SR15 found increases in flood frequency and extreme streamflow in some regions, but decreases in other regions. . . [H]ydrological literature on observed flood changes is heterogeneous, focusing at regional and sub-regional basin scales, making it difficult to synthesise at the global and sometimes regional scales. (Chapter 11.5)

AR6: [T]he seasonality of floods has changed in cold regions where snowmelt dominates the flow regime in response to warming (*high confidence*). Confidence about peak flow trends over past decades on the global scale is *low*. (Chapter 11.5)

NCA4: Trends in extreme high values of streamflow are **mixed** across the United States. Analysis of 200 U.S. stream gauges indicates areas of both increasing and decreasing flooding

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magnitude **but does not provide robust evidence** that these trends are attributable to human influences (pp. 240-241)

The absence of detectable US-wide trends in flooding is consistent with the findings in Section 6.4 of absence of coherent changes in extreme precipitation.

6.7 Droughts

Assessments of drought trends were as follows.

AR6: Few AR6 regions show observed increases in meteorological drought (Section 11.9, p. 1575),

AR6: Increasing trends in agricultural and ecological droughts have been observed on all continents (*medium confidence*), but decreases only in one AR6 region (*medium confidence*). Increasing trends in hydrological droughts have been observed in a few AR6 regions. (Chapter 11 Summary)

NCA4: As a consequence of this increased precipitation, **drought statistics over the entire CONUS have declined.** (p. 233)

NCA4: Recent droughts and associated heat waves have reached record intensity in some regions of the United States; however, by geographical scale and duration, the Dust Bowl era of the **1930s remains the benchmark** drought and extreme heat event in the historical record (very high confidence). (p. 231)

SREX: From a paleoclimate perspective, **recent droughts are not unprecedented**, with severe 'megadroughts' reported in the paleoclimatic record for Europe, North America, and Australia. (p. 170)

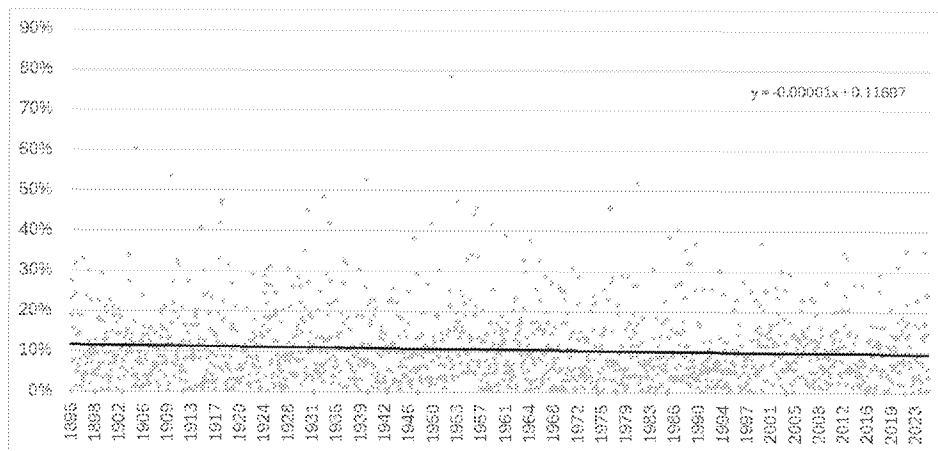


Figure 6.7.1: Monthly percent of US classified as “Very Dry” 1895—2025. Data source: NOAA [[HYPERLINK "https://www.ncei.noaa.gov/access/monitoring/uspa/wet-dry/0"](https://www.ncei.noaa.gov/access/monitoring/uspa/wet-dry/0)] least squares trendline added.

As shown in Figure 6.7.1, U.S. long-term data shows an insignificantly declining trend in extreme dryness (-0.001 percent per year)

Kogan *et al.* (2020) examines a 38-year high-resolution satellite-based drought measure and concludes that global drought has not intensified and is not connected to climate change: “it is possible to state firmly that global and main grain countries’ drought area and intensity trends have not been following global climate warming since 1980’s.”

In summary there is no evidence of increasing drought frequency or intensity in the U.S. or globally over recent decades.

6.8 Wildfires

The IPCC has not provided an assessment of wildfires. As shown in Figure 6.8.1, global wildfire activity as measured by European Space Agency shows a downward trend in the 21st century.

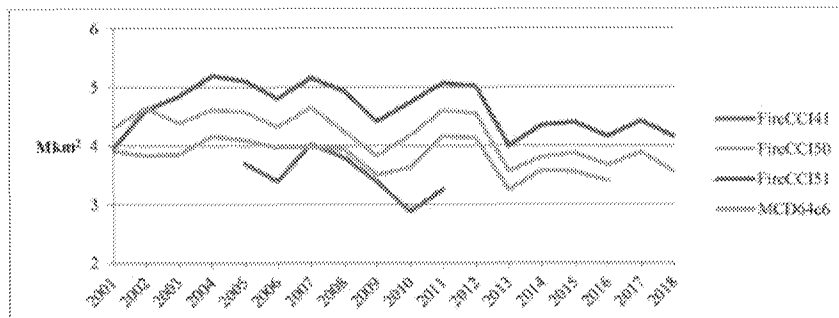


Figure 6.8.1: Global wildfire area 2001-2018. Source: From Lizundia-Loiola *et al.* (2021) Figure 12. The different coloured lines represent data products derived from different satellites and algorithms

Global data show that wildfire coverage is constant or declining on every continent (Samborska and Ritchie, 2024).

Active fire suppression since 1900 makes it difficult to establish a natural baseline for wildfire activity in the U.S. Paleoclimatic evidence indicates that past activity was much higher than today. Marlon *et al.* (2012) used sedimentary charcoal layers to reconstruct fire history of western U.S. for the past 1400 years and also fit a model to predict fire activity as a function of climatic conditions. Their results are summarized in Figure 6.8.2 below (from Figure 2 in their paper). There has been a growing wildfire deficit over the 20th century. In other words, however much fire was observed in the 20th century, it was less than what would have been observed in previous centuries based on the climatic conditions. Parks *et al.* (2025) likewise find

that despite the recent increase in wildfire burn area in North America, a significant wildfire deficit remains relative to historical wildfire regimes.

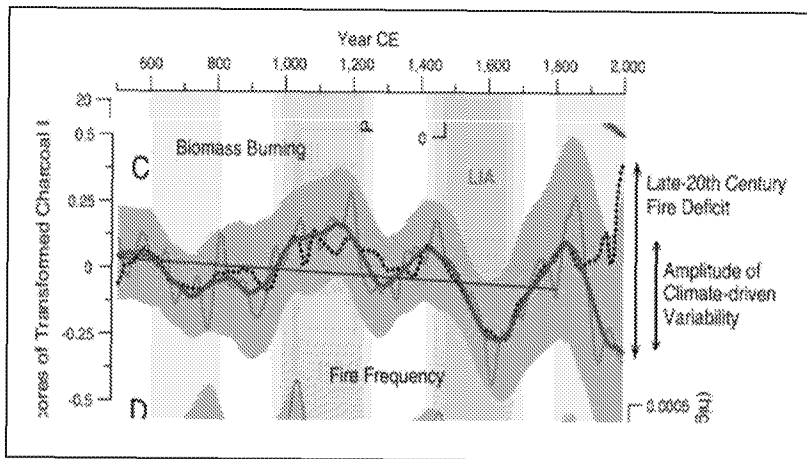


Figure 6.8.2 Fire frequency and fire deficit in the US. The red line shows the smoothed charcoal record and the black dotted line shows the predicted charcoal record based climatic conditions model. Source: Marlon *et al.* (2012) Figure 2.

U.S. data from the National Interagency Fire Centre (NIFC) from 1926 to 2023 are shown in Figure 6.8.3. The NIFC has removed the pre-1960 data from its current website on the grounds that measurement methods changed after 1960 making the comparison unreliable. Nonetheless just focusing on the post-1985 interval the number of fires is not increasing. The area burned did increase but only until about 2007.

Forest fires have always been a part of nature, and they can certainly create conditions that are inhospitable in the short term for all life, including humans. Science has confirmed the overall benefit and necessity of forest fires. While recent high-profile fires and seasons serve as a reminder of the potential destructive impact, the highest profile U.S. forest fire remains the 1910 Big Blowup fire in the U.S. west, which destroyed over three million acres and eliminated entire towns like Taft, MT (Apple, 2020). The 1910 fire reshaped the U.S. Forest Service (National Forest Foundation 2022) leading to a focus on fire suppression with a primary goal of defeating all forest fires (Forest History Society, 2022). This led to the “10 am rule” in 1935 requiring that all fires spotted on any day had to be controlled by 10 am the following day (National Forest Foundation, 2022).

While defeating all fires seemed a noble goal, questions began to arise as to whether this behavior “followed the science” (U.S. Forest Service, 2022). Over time the U.S. Forest Service has begun to rethink its goals, recognizing that new approaches such as prescribed burns, fuel elimination, and controlled wildfires are more appropriate (Sommer, 2016). Recent research is validating this approach and recognizing

that more frequent smaller fires likely result in healthier forests, water ecosystems and biodiversity (Stephens *et al.*, 2021).

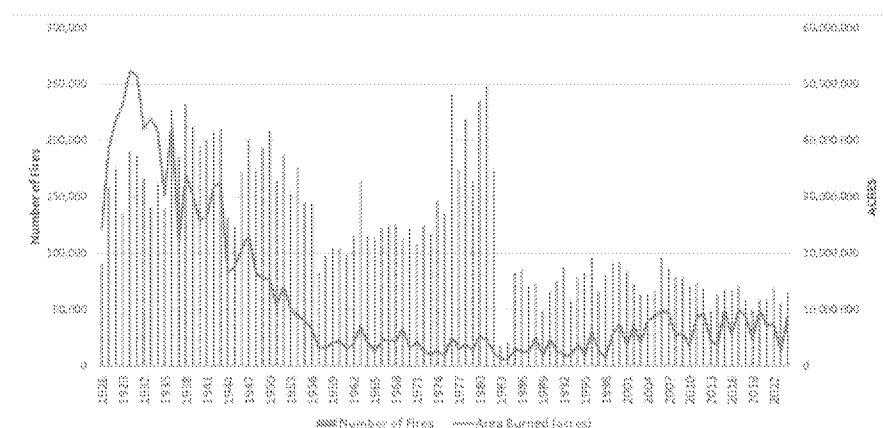


Figure 6.8.3: U.S. wildfires 1926 to 2023. Source: Post-2018: National InterAgency Fire Center data [[HYPERLINK "https://www.nifc.gov/fire-information/statistics/wildfires"](https://www.nifc.gov/fire-information/statistics/wildfires)]. Pre-2017 webarchive.org (n.d.).

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7 CHANGES IN SEA LEVEL

Chapter Summary

Since 1900, global average sea level has risen by about 8 inches. Sea level change along U.S. coasts is highly variable, associated with local variations in processes that contribute to sinking and also with ocean circulation patterns. The largest sea level ~~rise-increases~~ along U.S. coasts are Galveston, New Orleans, and the Chesapeake Bay regions - each of these locations is associated with substantial local land sinking (subsidence) unrelated to climate change.

Extreme projections of global sea level rise are associated with an implausible extreme emissions scenario and inclusion of poorly understood processes associated with hypothetical ice sheet instabilities. In evaluating the IPCC AR6 projections to 2050 (with reference to the baseline period 1995-2014), almost half of the sea level rise has already occurred by time has elapsed by 2025, with sea level rising ~~and~~ at a lower rate than predicted. U.S. tide gauge measurements ~~shown herein~~ reveal no obvious acceleration beyond the historical average rate of sea level rise. ~~TRIED TO REMOVE THE AMBIGUITY IN THE PREVIOUS SENTENCE~~

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7.1 Global sea level rise

Global sea level rise is arguably the most important climate impact driver that is unambiguously associated with increasing temperatures. At the global level, warming raises sea level through thermal expansion of sea water and through melting of glaciers and ice sheets. Variations in land water storage are another important factor. At the regional scale, sea level change is influenced by large-scale ocean circulation patterns, and geologic processes and deformation from the redistribution of ice and water. Locally, vertical land motion from geologic processes, ground water withdrawal, and fossil fuel extraction are also important.

The IPCC AR6 estimates that global mean sea level increased by 7.9 (5.9–9.8) inches between 1901 and 2018, with the rate of sea level rise accelerating in recent decades. At the ocean basin scale, sea levels have risen fastest in the Western Pacific and slowest in the Eastern Pacific over the period 1993–2018 (Fox-Kemper *et al.*, 2021). The rate of global sea level rise is estimated to be 0.12 inches/year, (about the height of two stacked pennies) (NASA, 2020).

The observing systems for global sea level rise have advanced significantly in the satellite era, particularly with the advent of satellite altimeters in 1993. Local tide gauges have provided useful data for the past century, and even longer for a few locations. Following the end of the Little Ice Age in the mid-nineteenth century, tide gauges show that the global mean sea level began rising during the period 1820–1860, well before most anthropogenic greenhouse gas emissions.

7.2 U.S. sea level rise

Observed and predicted rates of mean global sea level rise might have little scientific relevance for specific locations, owing to local processes (NOAA, 2025). Figure 7.1 shows that in Canada and Alaska (and also northern Washington), sea level is decreasing, owing to uplift from glacial rebound. Most of the Pacific coast tide gauges show low rates of sea level rise, while largest U.S. rates are on the Gulf coast (Louisiana and Texas) and in the mid-Atlantic states (Chesapeake Bay region).

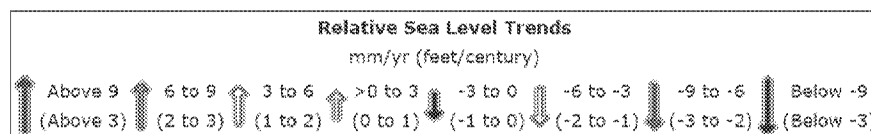


Figure 7.1. Map of rates of relative sea level rise along the U.S. coast (NOAA, <https://tidesandcurrents.noaa.gov/sltrends/>). For reference, 3 mm = 0.12 in.

Measurements of relative sea level rise from tide gauges conflate the climatologically relevant increase in the volume of seawater with local vertical land motion. The latter, which varies from place to place, is best measured using a Global Positioning System (GPS) station located near the tide gauge. It is driven by a range of processes that can be comparable to the climate signal and can locally exacerbate (subsidence/sinking) or mitigate (uplift) the risk of sea level rise (Wöppelmann and Marcos, 2016). Human activities triggering subsidence are often significant. They include soil drainage (*e.g.* for urban development purposes) and subsurface extraction of groundwater or hydrocarbons.

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Table 7.1 shows absolute sea-level rise (ASLR) for selected locations, determined from the sum of uncorrected sea-level rise as estimated from tide gauge time series (RSLR) (NOAA, 2025) and the vertical land motion (VLM) measurements (NAS, 2012; Letetrel *et al.*, 2015; Karegar *et al.*, 2016). The absolute sea level rise for each of these locations is significantly smaller than the measured relative sea level rise owing to local subsidence. More than half of the measured relative sea level rise is attributed to land sinking for these locations: San Francisco, Galveston, Grand Isle. For reference, the global average rate of absolute sea level rise is estimated to be 0.12 inches/year.

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Location	RSLR	VLM	ASLR
San Francisco, CA	+0.08	-0.06	+0.02
Galveston, TX	+0.26	-0.19	+0.07
Grand Isle, LA	+0.36	-0.28	+0.08
St Petersburg, FL	+0.12	-0.02	+0.10
New York City, NY	+0.11	-0.05	+0.06

Table 7.1 Absolute sea level rise (inches/year) consisting of Relative Sea Level Rise (RSLR) plus Vertical Land Motion (VLM)

San Francisco Bay

Over the past 100 years, relative sea level in the San Francisco Bay area has risen by 7.8 inches, at an average rate of 0.08 inches/year (Figure 7.2). As shown in Table 7.1, San Francisco's vertical land motion is -0.06 inches/year (sinking), producing a recent absolute rate of +0.02 inches/year. Portions of Treasure Island, San Francisco International Airport, and Foster City are sinking as fast as 0.4 inches/year (Shirzaei and Bürgmann, 2018). Problems in the San Francisco Bay area, including threats to the airport, are caused primarily by soil compaction in landfill zones that were formerly wetlands, not by the slow creep of global sea level rise.

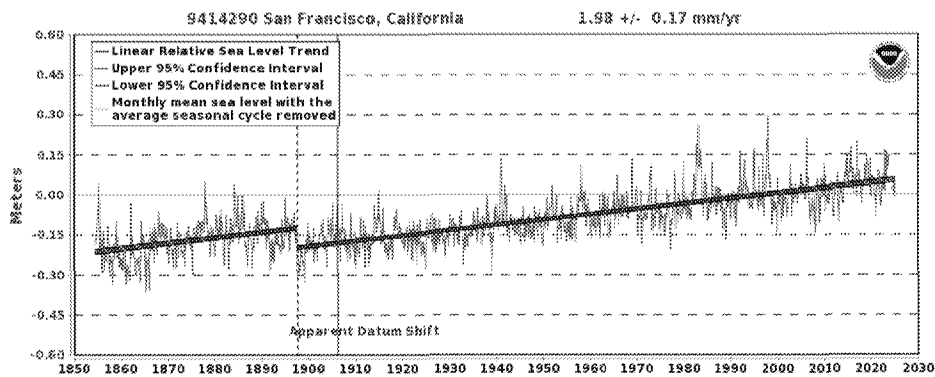


Figure 7.2. Tide gauge measurements at San Francisco, California, obtained from NOAA - https://tidesandcurrents.noaa.gov/strends/strends_station.shtml?id=9414290 (downloaded 4/22/25).

Galveston - Houston

Long-term tide measurements at Galveston Pier 21 show sea level rise of 2.18 feet in the past century, or a rate of 0.26 inches/year (Figure 7.3). Vertical land motion (subsidence) at Galveston is estimated at -0.19 inches/year, yielding an absolute rate of rise of +0.07 inches/year (Table 7.1). The U.S. Geologic Survey found that most of the land-surface subsidence in the Houston-Galveston region is a direct result of groundwater withdrawals (Kasmarek and Ramage 2017), which caused compaction of the aquifer

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sediments, mostly in the fine-grained silt and clay layers. By 1979, as much as 10 feet of subsidence had occurred in Houston.

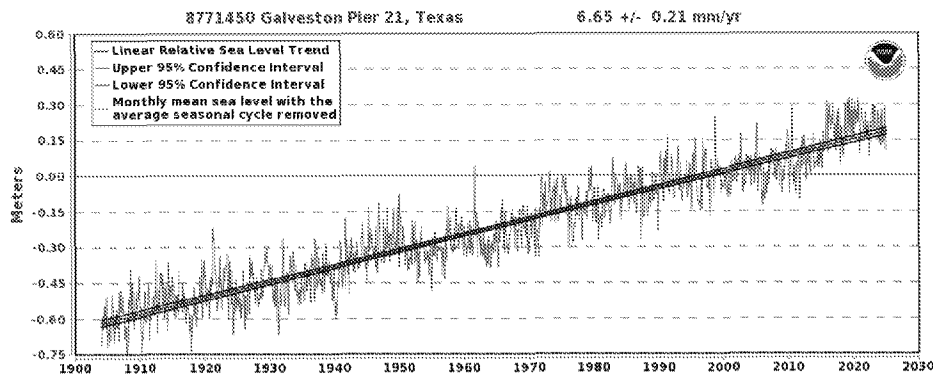


Figure 7.3. Tide gauge measurements Galveston Pier, TX, obtained from NOAA - https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8771450 (downloaded 4/22/2025).

New Orleans and the Mississippi delta

Long-term tide gauge measurements at Grand Isle, Louisiana, show that sea level has risen by slightly more than 3 feet over the last 100 years at an average rate of 0.36 inches/year (Figure 7.4). Vertical land motion (subsidence) is estimated -0.28 inches/year. Table 7.1 gives the absolute sea level rise as +0.08 inches/year.

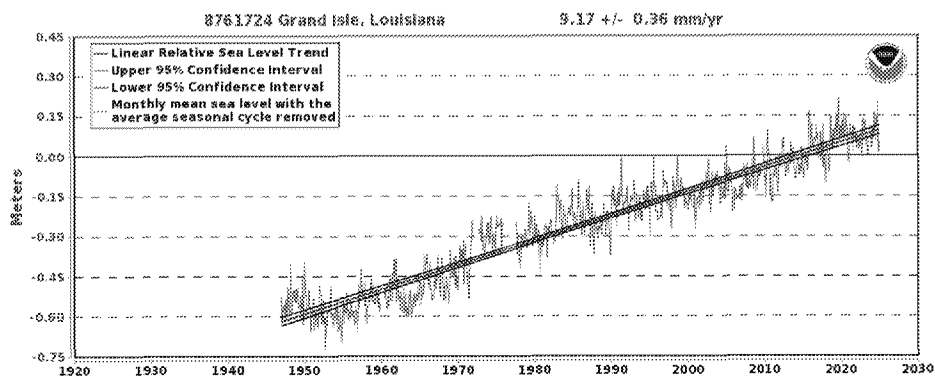


Figure 7.4. Tide gauge measurements at Grand Isle, LA, obtained from NOAA - https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8761724 (downloaded 4/22/25).

The issues of sea level rise and land loss in the Mississippi Delta region are complex, with geological subsidence and the decline in sediment transported by the Mississippi River being the dominant drivers. The construction of dams in the basin since the 1950s has decreased the Mississippi's suspended sediment load by ~50 percent (Maloney 2018). A new subsidence map of coastal Louisiana finds the coastal region to be sinking at about one third of an inch per year (Neinhuis *et al.* 2017), associated with groundwater and resource withdrawal. As the city's elevation averages one to two feet *below* sea level, sea level rise from anthropogenic warming is hardly the dominant driver of New Orleans' problems.

New York City

New York City is particularly vulnerable to the effects of sea level rise because it is built primarily on islands and has 520 miles of coastline. Measurements by a tide gauge at the southern tip of Manhattan (The Battery) show that relative sea level has risen over 11 inches over the past century, at an average rate of 0.11 inches/year (Figure 7.5). But vertical land motion in the New York City area is -0.05 inches/year (roughly 5 inches per century), so that the absolute rate of sea level rise at The Battery is 0.06 inches/year, or about 55 percent of the measured relative sea level rise.

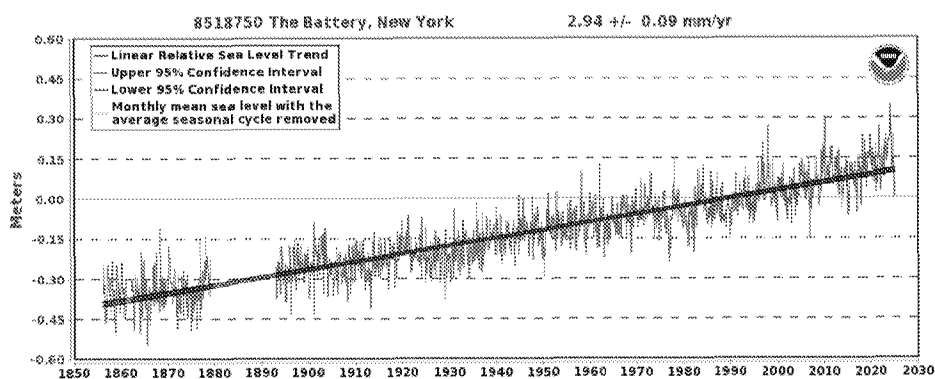


Figure 7.5. Tide gauge measurements at The Battery, New York, obtained from NOAA - https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8518750 (downloaded 4/22/25).

7.3 Projected sea level rise

The concern over sea level rise is not about the roughly eight inches of global rise since 1900. Rather, it is about projections of *accelerated* rise based upon simulations of a warming climate through the 21st century.

The IPCC AR6 finds *high agreement* across published global mean sea level projections for 2050 with little sensitivity to emissions scenarios. Considering only projections incorporating ice-sheet processes in whose quantification there is at least *medium confidence*, the global sea level projections for 2050, across all emissions scenarios, fall between 3.94 and 15.75 inches (5th–95th percentile *very likely* range) relative to the 1995–2014 baseline period (Fox-Kemper *et al.*, 2021).

Conversely, AR6 states there is *low agreement* across published global mean sea level projections for 2100, particularly for higher emissions scenarios. Considering only projections representing ice sheet processes in whose quantification there is at least *medium confidence*, the AR6 global mean sea level projections for 2100 lie between 7.87 and 39.37 inches (5th–95th percentile *very likely* range) under the medium emissions scenario SSP2–4.5 (Fox-Kemper *et al.*, 2021). There is deep uncertainty surrounding projections of sea level rise to 2100 owing to uncertainties in ice sheet instabilities, particularly for the higher emissions scenarios.

In February 2022, NOAA issued its projections of sea level rise for various sites along the U.S. coast (Sweet *et al.*, 2022). They claim that by 2050, the sea will have risen one foot at The Battery in Manhattan (relative to 2020). A one-foot rise in thirty years would be more than twice the current rate and about three times the average rate over the past century. In that historical context, NOAA’s projection is remarkable—as shown in Figure 7.6, it would require a dramatic acceleration beyond anything observed since the early 20th century. But even more noteworthy is that Sweet *et al.* (2022) say this rise is “locked in”—it will happen no matter what future emissions are. We should know in a decade or so whether that prediction has legs.

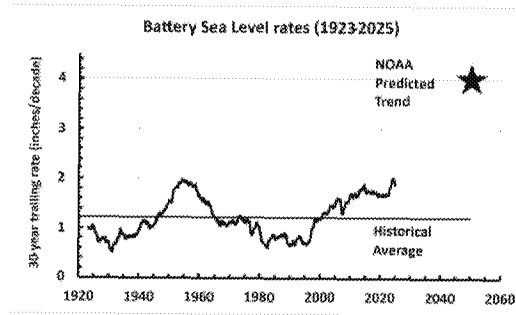


Figure 7.6 Rate of sea level rise at the Battery in Manhattan. Shown is the historical thirty-year trailing trend, together with the allegedly “locked in” NOAA predicted trend for 2050. Historical data: NOAA Tides and Current.

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8 UNCERTAINTIES IN CLIMATE CHANGE ATTRIBUTION

Chapter summary

“Attribution” refers to identifying the cause of some aspect of climate change, specifically with reference to anthropogenic activity. There is an ongoing scientific debate around attribution methods, particularly regarding extreme weather events. Attribution is made difficult by high natural variability, the relatively small expected anthropogenic signal, lack of high-quality data, and reliance on deficient climate models. The IPCC has long cautioned that methods to establish causality in climate science are inherently uncertain and ultimately depend on expert judgement.

Substantive criticism of the main IPCC assessments of the role of CO₂ in recent warming focus on inadequate assessment of natural climate variability, uncertainties in measurement of solar variability and in aerosol forcing, and problems in the statistical methods used for attribution.

The IPCC does not make attribution claims for most climate impact drivers related to extreme events. Statements related to statistics of global extremes (*e.g.* event probability or return times, magnitude and frequency) are not generally considered accurate owing to data limitations and are made with low confidence. Attribution of individual extreme weather events is challenging due to their rarity. Conflicting claims about the causes of the 2021 Western North America Heatwave illustrate the perils of hasty attribution claims about individual extreme events.

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8.1 Introduction

The Intergovernmental Panel on Climate Change (IPCC) distinguishes between detection of climate change and attribution of its cause. As defined by the IPCC-AR6 WGI Glossary (IPCC, 2025):

Detection: Detection of change is defined as the process of demonstrating that climate or a system affected by climate has changed in some defined statistical sense, without providing a reason for that change. An identified change is detected in observations if its likelihood of occurrence by chance due to internal variability alone is determined to be small, for example, <10%.

Attribution: Attribution is defined as the process of evaluating the relative contributions of multiple causal factors to a change or event with a formal assessment of confidence.

Both detection and attribution rely on statistical analysis. Detection focuses on whether changes are significant enough to stand out from random variation regardless of cause. Attribution involves comparison of observed events to model-generated counterfactuals. Since experimentation on the climate is not possible, attribution requires statistical inference to assess how much human activities, (such as GHG emissions), versus natural factors, (like volcanic eruptions), contribute to observed changes. Attribution methods assume all external and internal drivers of the system are known and represented.

There are ongoing scientific debates around attribution methods, especially those for attributing extreme weather events to climate change. The IPCC has long cautioned that methods to establish causality in climate science are inherently uncertain and ultimately depend on expert judgement. AR4 Working Group I (Hegerl *et al.*, 2007) explained it as follows:

‘Attribution’ of causes of climate change is the process of establishing the most likely causes for the detected change with some defined level of confidence... unequivocal attribution would require controlled experimentation with the climate system. Since that is not possible, in practice attribution of anthropogenic climate change is understood to mean demonstration that a detected change is ‘consistent with the estimated responses to the given combination of anthropogenic and natural forcing’ and ‘not consistent with alternative, physically plausible explanations of recent climate change that exclude important elements of the given combination of forcings’ (IPCC, 2001)... The approaches used in detection and attribution research described above cannot fully account for all uncertainties, and thus ultimately expert judgement is required to give a calibrated assessment of whether a specific cause is responsible for a given climate change.

AR5 Working Group II (Cramer *et al.*, 2014) makes the following statement:

Two broad challenges to the detection and attribution of climate change impacts relate to observations and process understanding. On the observational side, high-quality, long-term data relating to natural and human systems and the multiple factors affecting them are rare. In addition, the detection and attribution of climate change impacts requires an understanding of the processes by which climate change, in conjunction with other factors, may affect the system in question.

Because of the complexity of the causal chains in the climate system, investigation of these relationships is exceptionally challenging.

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8.2 Attribution methods

The IPCC employs several attribution methods to assess the causes of observed climate changes, distinguishing between natural and human-induced factors. Below is a concise description of the key IPCC attribution methods.

Optimal Fingerprinting uses linear regression to explain variations in observed climate data as a weighted sum of climate model simulations run with and without anthropogenic forcings. The data used in the regression model is weighted to try to minimize the influence of random noise and the estimation method is chosen to account for climate model error.

Time Series Analysis exploits statistical differences between anthropogenic forcing and natural variability to see which dominates observed temperatures and also uses variations in the timing of changes to determine if causal dependence across data series can be inferred.

Process-Based Attribution focuses on understanding the physical mechanisms behind observed changes. This approach combines observations, climate models, and theoretical understanding to attribute changes in specific processes to forcings. This approach is often used for regional climate phenomena, such as monsoon changes or polar amplification

Extreme Event Attribution assesses the role of human influence in the likelihood of occurrence or intensity of extreme weather events (*e.g.* heat waves or droughts). Methods include:

- Probabilistic Event Attribution uses large ensembles of climate model simulations to compare observed events to model-generated counterfactuals
- Storyline Approach examines the physical processes driving an event and evaluates how anthropogenic forcings might have modified those processes

8.3 Attribution of global warming

Attribution statements for global warming in the three most recent IPCC Assessment reports are:

AR4: **Most of the observed increase** in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations. (IPCC 2007)

AR5: It is *extremely likely* that **more than half of the observed increase** in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together. The best estimate of the human-induced contribution to warming is similar to the observed warming over this period. (IPCC 2013)

AR6: The *likely* range of total human-caused global surface temperature increase from 1850–1900 to 2010–2019 is 0.8°C to 1.3°C, with a best estimate of 1.07°C. It is *likely* that well-mixed GHGs contributed a warming of 1.0°C to 2.0°C, other human drivers (principally aerosols) contributed a cooling of 0.0°C to 0.8°C, natural drivers changed global surface temperature by –0.1°C to +0.1°C, and internal variability changed it by –0.2°C to +0.2°C. It is *very likely* that **well-mixed GHGs were the main driver** of tropospheric warming since 1979. (IPCC 2021)

The AR4 and AR5 attribution statements reference the warming since the mid-20th century, the period when greenhouse gas emissions began ~~rapidly~~ increasing rapidly. The words “most” and “more than half” are deliberately imprecise, potentially ranging from 51 to 99 percent of the warming – presumably this imprecision is to account for structural uncertainties such as natural internal variability. The confidence level increases from *very likely* to *extremely likely* from AR4 to AR5. The structure of the attribution statement in the AR6 is fundamentally different, referencing the warming to the period 1850–1900. The AR6 attribution statement is more precise numerically, but with a lower level of confidence at “likely” – the AR6 attributes essentially all the warming to increases in greenhouse gases. The most confident statement from the AR6 relates to the tropospheric warming since 1979, using the words “main driver” and “very likely.”

There are three areas of substantive criticism of the IPCC’s assessment of the causes of the recent warming: inadequate assessment of natural climate variability, inappropriate statistical methods, and substantial discrepancies between models and observations. The last is discussed in Chapter 5, while this chapter discusses the first two factors. All of these criticisms are relevant to the IPCC’s policy-informing attribution of the recent warming, which also underpins extreme event attribution

8.3.1 Natural climate variability

IPCC-AR6 states that natural external drivers since 1850–1900 have changed global surface temperature by –0.1°C to +0.1°C, and internal variability has changed it by –0.2°C to +0.2°C – on average having essentially no net impact on the warming since 1850–1900. As discussed below, this minimal contribution of natural variability has been disputed by several publications that question the magnitudes of solar variability and internal variability from large-scale ocean circulations.

Solar variability

IPCC-AR5 concluded that the best estimate of radiative forcing due to Total Solar Irradiance (TSI) changes over the period 1750–2011 was very small (0.05 W/m², Myrhe *et al.*, 2014). IPCC-AR6 acknowledges substantially higher values and a much larger range of estimates of changes in TSI over the last several centuries, stating that the TSI between the Maunder Minimum (1645–1715) and the second half

of the twentieth century increased by 0.7–2.7 W/m², a range that includes both low and high variability TSI data sets (Gulev, 2021). However, the recommended forcing dataset for the CMIP6 climate model simulations used in AR6 for attribution studies averages two data sets with low solar variability (Matthes, 2017).

While AR6 shows a substantially greater solar impact than does AR5, the overall impact of solar forcing on the climate was still assessed to be small compared to anthropogenic forcing. However, the impact of solar variations on the climate is uncertain and subject to substantial debate (Lockwood, 2012; Connolly *et al.*, 2021) – something that is not evident from in the IPCC assessment reports.

The variations of TSI over time remains a challenging problem. Since 1978, there have been direct measurements of TSI from satellites. However, the data exhibits non-negligible inconsistencies, and interpreting any multi-decadal trends in TSI requires comparisons of observations from overlapping satellites. There are several rival composite TSI datasets, ~~disagreeing that disagree~~ as to whether TSI increased or decreased during the period 1986–96 (the ACRIM gap; see Chapter 4). Further, the satellite record of TSI is used to calibrate proxy models, ~~that infer whereby~~ past solar variations are inferred from sunspots and cosmogenic isotope measurements (Velasco Herrera *et al.*, 2015).

There is substantial evidence for high solar activity in the second half of the 20th century (starting in 1959) and extending into the 1990's, before a decline in the early 21st century; this period is often termed the “Modern Maximum.” (Chatzistergos *et al.*, 2023; Solanki *et al.*, 2004; Usoskin *et al.*, 2007). However, some scientists have concluded that it is not possible to be confident of any multi-decadal trend in TSI (Schmutz, 2021).

This uncertainty causes some reconstructions of TSI from 1750 to have low variability (implying a very low impact of solar variations on global mean surface temperature) whereas datasets with high TSI variability can explain more than 70 percent of the temperature variability since preindustrial times (Scafetta, 2013; Stefani, 2021). The choice of TSI satellite record used in an analysis can therefore substantially influence how much climate change is attributed to human versus natural forcings.

There is growing evidence that other aspects of solar variability, which are referred to as solar indirect effects, either amplify TSI forcing or are independent of TSI forcing. Scafetta *et al.* (2023) suggests that ~80 percent of solar influence on climate ~~may-might~~ stem from non-TSI mechanisms. There are numerous candidate processes, including solar ultraviolet changes; energetic particle precipitation; atmospheric-electric-field effect on cloud cover; cloud changes produced by solar-modulated galactic cosmic rays; large relative changes in the magnetic field; and the strength of the solar wind. Such solar indirect effects are not included in climate models, although indirect methods of estimating their impacts suggest they are significant. However, claims of non-TSI mechanisms influencing climate are uncertain and debated.

Natural variability of large-scale ocean circulations

Variations in global mean surface temperature are linked to recurrent large-scale variations in ocean circulation patterns, including the Atlantic Multidecadal Oscillation (AMO), the Pacific Decadal Oscillation (PDO) and the El Niño-Southern Oscillation (ENSO). These circulations influence ocean heat uptake and heat distribution and also influence atmospheric circulation patterns and cloud distributions. There is some debate as to whether these variations are strictly internal to the climate system, or whether this variability can have a solar/astronomical origin or can be influenced by large volcanic eruptions.

While climate models simulate the large-scale ocean circulations and internal climate variability, most models have too little amplitude compared to observations at multi-decadal frequencies and phasing out-of-sync with the observed climate (Kravtsov *et al.* 2024). Averaging multiple simulations effectively averages out the internal variations, leaving only the forced climate variability (*e.g.* CO₂ forcing). With

most of the modern warming beginning in the late 1970's, the recent 50-year warming is on the same time scale as the multi-decadal oscillations of the AMO and PDO.

Here are summary statements from the IPCC AR5 and AR6 reports:

AR5: Decadal variability in the Pacific, associated with the PDO or IPO [Interdecadal Pacific Oscillation], contributes significantly to regional and global temperature trends, but the relative contributions of internal variability and external forcing are difficult to disentangle in CMIP5 simulations.

AR6: Since AR5, there has been increased understanding of the role of internal variability, such as ENSO, PDO, and AMO, in modulating regional climate trends. However, limitations in simulating the exact timing and amplitude of these modes in CMIP6 models contribute to uncertainties in attributing observed changes to anthropogenic forcing (*high confidence*).

The amplitude of the peak-to-trough impact of the multi-decadal oscillations on global temperatures has been assessed by the IPCC AR6: "The likely range of change due to internal variability is -0.2°C to +0.2°C (IPCC, 2021)." This implies a trough-to-peak change of 0.4°C. Over many centuries, any global temperature changes from the troughs and peaks will cancel out, with little to no net impact.

However, with a nominal timescale of 60-80 years for oscillations such as the AMO and PDO, the timing of the peaks and troughs can be confused with the secular trend. This becomes very relevant for attributing the warming for the past 50 years, when most of the recent warming has occurred. Even if climate models have the correct amplitude of the multidecadal oscillations, the timing of the peaks and troughs is not adequately simulated, with each model and individual ensemble simulating a different phasing. Once the simulations of the ensemble members and different models are averaged, the natural internal variability contribution is averaged out owing to differences in phasing, effectively cancelling the role of natural internal variability in the attribution process.

The time series of global surface temperature anomalies since 1850 (Figure 8.1) shows irregular variations of significant amplitude against the background of an overall warming trend and, after 1976, a pronounced difference in trends between the Northern Hemisphere and the Southern Hemisphere. The period between 1905-1945 shows a strong trend of warming. The following thirty years from 1945-1976 showed slightly declining temperatures. The most recent warming period started in 1977.

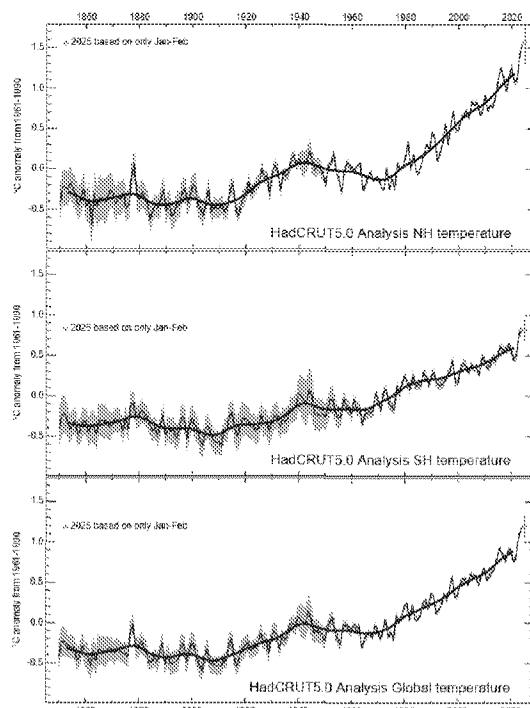


Figure 8.1 Global average surface temperature anomalies 1850—2025. Top: Northern hemisphere. Middle: Southern hemisphere. Bottom: Global average. Source: UK Hadley Centre [[HYPERLINK "https://crudata.uea.ac.uk/cru/data/temperature/HadCRUT5.0Analysis.pdf"](https://crudata.uea.ac.uk/cru/data/temperature/HadCRUT5.0Analysis.pdf)]

The causes of the early 20th century warming are discussed by Hegerl *et al.* (2017; 2019). The atmospheric CO₂ concentration increased from 298 ppm in 1905 to 310 ppm in 1941, implying that CO₂ had little impact. Volcanic activity during this period was very low, and solar forcing is uncertain. Yet Hegerl *et al.* (2017) somehow inferred that 40–54 percent of this warming could be attributed to external forcing, with the rest associated with internal variability. Bronniman *et al.* (2024) focused on the causes of the cooling in the first decade of the 20th century in the Southern Hemisphere. They found that the cooling was related to a La-Niña-like pattern in the Pacific, a cold tropical and subtropical South Atlantic, a cold extratropical South Pacific, and cool southern midlatitude land areas. The Southern Annular Mode was positive, with a strengthened Amundsen–Bellingshausen seas low, although the spread of the data products is considerable.

The warming in the 1930's and subsequent cooling during mid-century was particularly pronounced in the Arctic. Bokuchava and Semenov (2021) find that these variations were most likely caused by a combined effect of long-term natural climate variations in the North Atlantic and North Pacific with a contribution of the natural radiative forcing related to the reduced volcanic activity and variations of solar activity, as well as growing greenhouse gases concentrations. Tokinaga *et al.* (2017) showed that the combined effect of internally generated Pacific and Atlantic interdecadal variability intensified Arctic

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warming in the early 20th century. The synchronized Pacific-Atlantic warming drastically alters planetary-scale circulations over the Northern Hemisphere; these same circulation patterns have a global influence.

The cooling period between 1945 and 1976 has been referred to as the “grand hiatus.” Numerous causes have been hypothesized: natural internal variability from fluctuations associated with the Pacific Decadal Oscillation and Atlantic Multidecadal Oscillation; cooling from increased emissions of aerosols from industrial activities; increased heat uptake in the Atlantic, Southern and Equatorial Pacific Oceans. Thompson *et al.* (2010) find that the hemispheric differences in temperature trends in the middle of the twentieth century stem largely from a rapid drop in Northern Hemisphere sea surface temperatures of about 0.3 °C between about 1968 and 1972.

The Great Pacific Climate Shift of 1976-1977 was a notable climatic event characterized by an abrupt change in the North Pacific Ocean's atmosphere-ocean system that interacted with global climate patterns. This shift is closely associated with the Pacific Decadal Oscillation (PDO) that oscillates between warm and cool phases over decades. The 1976 shift marked a transition from a predominantly negative (cool) PDO phase (1947–1976) to a positive (warm) phase (1977 through 2000), with significant implications for global and regional climate patterns, including the frequencies of El Niño and La Niña events. The Great Pacific Climate Shift coincided with the beginning of a period of accelerated global warming. When the Great Pacific Climate Shift is accounted for in climate attribution analyses since 1950, 40 percent or more of the warming in the second half of the 20th century is attributed to natural internal variability (McLean *et al.*, 2009; Tung and Zhou, 2013; Chylek *et al.*, 2016; Scafetta, 2021).

8.3.2 Optimal fingerprinting

Optimal fingerprinting is a statistical technique introduced by Allen and Tett (1999) that compares observed climate data to climate model simulations to identify patterns (or “fingerprints”) associated with human or natural forcing. It involves taking a vector of observed climate changes, such as warming rates in locations around the world, and decomposing them into a weighted sum of “signals”, which are analogues to the observations generated by climate models with different types of forcings. The weights are chosen using a regression method called Total Least Squares (TLS). The analysis commonly uses just two signals, one generated by models using only anthropogenic forcings and one using only natural forcings. If the estimated weighting coefficient attached to a signal is significantly different from zero, then that signal is said to be “detected”. If it is close to 1.0, then the model generating the signal is said to be consistent with observations. If it is less than 1.0, then the model signal for that forcing is too strong and needs to be scaled down, and vice-versa. Both the observed data and the signals are weighted using a model-generated estimate of patterns of randomness in the climate system so as, in principle, to put maximum weight on regions where natural variability is minimized.

Optimal fingerprinting is the primary tool for attribution in the research literature. While it has been widely used and prominently featured by the IPCC since 2001, there is very little literature examining the statistical properties of the results it generates. One of its inherent weaknesses is that results depend on assumptions about the accuracy of climate models, especially regarding their representation of natural variability (IPCC AR5 Ch 10.2.3).

A series of papers by McKittrick (McKittrick 2021, 2022, 2023, 2025) has challenged the optimal fingerprinting method, arguing that it is inherently unreliable and that practices adopted from econometrics can provide more valid results. Statistical theory requires that for regression models to yield unbiased coefficients, a set of assumptions called the Gauss-Markov conditions must hold. McKittrick (2021) argued that the Allen and Tett (1999) methodology violates the Gauss-Markov conditions, leading to potentially biased and inconsistent fingerprinting coefficients, undermining the reliability of the method. Chen *et al.* (2023) confirmed this analysis, although they argued that the method could yield valid results under very stringent assumptions. McKittrick (2022) and (2023) raised a further concern that climate scientists—virtually alone among

scientific disciplines—have used an estimation method called Total Least Squares (TLS) to estimate anthropogenic greenhouse gas signal coefficients, despite its tendency to be unstable unless some strong assumptions hold that in practice are unlikely to be true. Under conditions that easily arise in optimal fingerprinting, TLS estimates have a large positive bias. Thus, any study that used TLS for optimal fingerprinting without verifying its applicability in the specific data context has likely overstated the attribution.

McKittrick (2025) presented an empirical example comparing the results of conventional optimal fingerprinting against methods drawn from mainstream econometrics that are known to be valid for the specific application of signal detection. While the IPCC optimal fingerprinting method yields an anthropogenic signal coefficient close to 1.0 on a global temperature data set spanning 1900 to 2010, consistent estimation yields a coefficient around 0.4, which rises to about 0.65 on data spanning 1980 to 2010, implying the model response to greenhouse gases needs to be scaled down by about half to optimally match observations. The natural forcing signal coefficient, by contrast, is between 2.0 and 4.0, implying the climate model signals of natural forcing need to be scaled up two-to four-fold to match observed climate change. The fingerprinting coefficients estimated in McKittrick (2025), when used to scale the average sensitivity of the climate models used to generate the forcing signals in his data set, imply a Transient Climate Sensitivity of 1.4°C, which is consistent with the estimate by Lewis (2023) using a different estimation method and multiple independent data sets.

While these analyses do not falsify results stemming from the IPCC optimal fingerprinting method, they do challenge the basis on which they were believed to be correct.

8.3.3 Time series methods

The IPCC (AR5 WGI 10.2.2) drew attention to alternative approaches of assessing causality that emerged from the time series econometrics literature. These have the advantage of not depending on assumptions about the accuracy of climate models, but the disadvantage that they depend on difficult-to-test assumptions about the data generating process underlying climate and forcing data. The methods, now referred to as climate econometrics, use the tools of unit root testing, Granger causality and cointegration analysis, all of which are familiar in economics and finance and which are slowly being adopted in climate science. Time series analysis methods hold out the possibility of determining whether anthropogenic or natural forcings are the primary drivers of climate change without requiring the use of climate models, although key questions remain unsettled (e.g. Dergiades *et al.*, 2016, Balcombe *et al.*, 2019, Dagsvik *et al.*, 2020, Razzak, 2022, Dagsvik and Moen, 2023).

“Granger causality” modeling is a tool for determining directions of influence in data series that move together. It is a statistical, not a physical, concept. If knowing the current value of one variable significantly improves the forecast accuracy of another variable, we can infer a causal connection exists; this is called Granger causality. The modeling tools, called vector autoregression, measure direct impulse-response patterns and feedbacks. An application to the well-known Vostok ice core data revealed an error in Al Gore’s documentary *An Inconvenient Truth*. Gore showed the data and drew attention to the coherence of temperature and CO₂ changes over a 440,000 year span, which he asserted was due to CO₂ driving temperature changes. But temperature changes can also affect atmospheric CO₂ levels. Davidson *et al.* (2015) examined the series and found that temperature Granger causes CO₂ but not the reverse. In other words on the time scales represented in the Vostok data, the coherence in the series is primarily due to the influence of temperature on CO₂ levels, not the feedback of CO₂ levels on temperature.

In summary, the primary statistical methods for attributing causation in climate data are optimal fingerprinting and time series analysis. Applications of the Allen and Tett (1999) optimal fingerprinting method dominate the attribution literature and have underpinned past IPCC conclusions, but results depend

on the accuracy of climate models and the method has recently been criticized as inherently biased. Time series methods do not depend on climate models but require assumptions of their own and have generated results that have thus far not converged on a consensus.

8.4 Declining planetary albedo and recent record warmth

A sharp recent increase in global average temperatures has raised the question of short-term drivers of climate. One such candidate is the fraction of absorbed solar radiation which has also increased abruptly in recent years. The question is whether the change is an internal feedback to warming caused by greenhouse gases, or whether something else increased the fraction of absorbed radiation which then caused the recent warming.

The planetary albedo is the fraction of incoming solar radiation that is reflected back into space rather than being absorbed by the planet. Highly reflective surfaces like cloud tops and snow and ice are most important in this regard. The Earth's albedo is approximately 30 percent, meaning almost a third of the sunlight that reaches Earth is directly reflected back to space. A lower albedo implies more solar energy is absorbed by the planet to be then re-radiated as heat. Hence, other things being equal, a decline in planetary albedo is associated with a warming of the Earth.

Arguably the most striking change in the Earth's climate system during the 21st century is a significant reduction in planetary albedo since 2015, which has coincided with at least two years of record global warmth. Figure 8.2 shows the planetary albedo variations since 2000, when there are good satellite observations. The 0.5 percent reduction in planetary albedo since 2015 corresponds to an increase of 1.7 W/m² in absorbed solar energy-power averaged over the planet (Hansen and Karecha, 2025). For comparison, the IPCC estimate of forcing from the increase in atmospheric CO₂ compared to preindustrial times is approximately 2.2 W/m² (Figure 3.1.2).

Looking back prior to 2000 with less adequate data, Goessling *et al.* (2025) assessed that the planetary albedo was relatively low around the 1940's and 50's, before rising industrial aerosol precursor emissions increased the albedo until the 1980's. The strongest planetary albedo excursions were high-albedo episodes caused by volcanic eruptions, such as after the Mount Pinatubo eruption in 1991. Although uncertain, the 2023 planetary albedo minimum ~~may-might~~ have been the lowest since at least 1940.

Changes in surface characteristics cannot explain this decrease in planetary albedo since 2015:

- Arctic sea ice extent has declined by about 5 percent since 1980 (https://nsidc.org/data/seaice_index/images/s_plot_hires.png), although following 2007 there has been a pause in the Arctic sea ice decline (England *et al.*, 2025)
- Regarding Antarctic sea ice, the IPCC AR6 concludes that "There has been no significant trend in Antarctic sea ice area from 1979 to 2020 due to regionally opposing trends and large internal variability." (Summary for Policymakers, A.1.5)
- Northern hemispheric annual snow cover has been slowly declining since 1967, with barely significant trends. The data show the Northern Hemisphere has snowier winters, accompanied by more rapid melt in spring and summer. [HYPERLINK "<http://climate.rutgers.edu/snowcover/>"] and Section 5.6
- Global greening (Chapter 2) is contributing to the decrease in planetary albedo, as forests have a lower albedo than open lands or snow. However, there is some evidence that forests increase cloud cover (high reflectivity), which counteracts the direct albedo ~~increase-decrease~~ associated with increasing forested area.

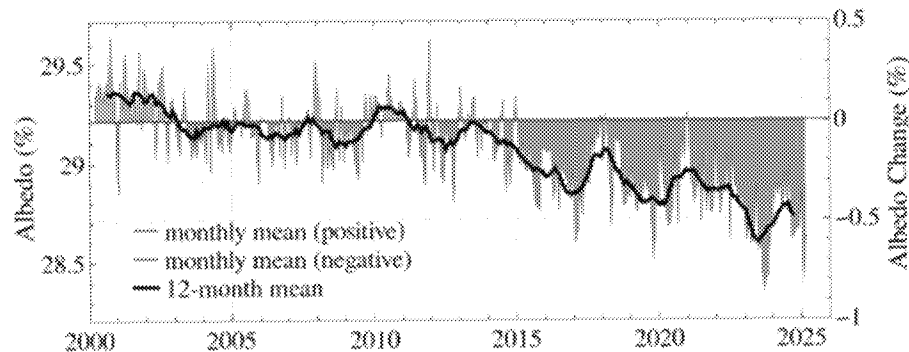


Figure 8.2. Earth's albedo (reflectivity, in percent), with seasonality removed. From Hansen and Karecha (2025)

Changes in surface reflectivity are contributing to a small, slow decline in planetary albedo. However, these changes cannot explain the sharp decline in planetary albedo beginning in 2015. Further, any changes in surface albedo are effectively damped by about a factor of three³ on average, primarily due to cloud masking (Loeb *et al.* 2019). Surface albedo changes have thus contributed only weakly to the recent planetary albedo decline, particularly when averaged annually and globally. This leaves the most likely explanation for the sharp albedo decline as changes in atmospheric aerosols and/or clouds.

Aerosols are small particles in the atmosphere that reflect sunlight and can interact with cloud processes to make the clouds more reflective. Aerosols have both natural origins (e.g. dust from soils, wildfires) as well as human origins from combustion (including fossil fuels). Regions that are greening and/or have an increase in rainfall might be producing less dust. For anthropogenic aerosols, new ship fuel regulations aimed at reducing sulfur emissions were implemented in three phases, in 2010, 2015 and 2020. Sulfate particles reflect solar radiation. Cleaner air means less solar radiation is reflected, which contributes to surface warming. Indirect effects of sulfate aerosols include increasing the reflectivity of low-level clouds in the subtropics. There is controversy surrounding the importance of this change in sulfate emissions to the Earth's radiation balance (Hodnebrog *et al.*, 2024; Yuan *et al.*, 2024), but the restriction of this effect to major shipping routes suggests a small global impact (Schmidt, 2024).

Changes in clouds are the primary candidate to explain the decline in global albedo since 2015. Two recent papers (Loeb *et al.*, 2024; Goessling *et al.* 2024) have addressed recent variations in cloud properties. By considering satellite and reanalysis data, Loeb *et al.* found that decreases in low- and mid-level clouds since 2015 are the primary reason for decreasing planetary albedo in the Northern hemisphere, whereas in the Southern hemisphere the decrease in planetary albedo is primarily due to decreases in mid-level clouds across all latitude zones. Goessling *et al.* (2024) found that cloud anomalies were mainly due to reduced low-level clouds. Regions with coherent low-level cloud reductions over the past decade include the warm pool region around the Maritime Continent and the northern extratropical western Pacific, as well as large parts of the Atlantic and adjacent land regions. The reduction of global cloud cover identified in these analyses since 2015 is 1-2 percent.

The issue then becomes the causes of the change in cloud cover. Two causes have been posited for the declining cloud cover over the past decade:

- Natural climate variability

- Changes in low cloud cover associated with warming sea surface temperatures, implying an emerging positive feedback to climate change (Hansen and Karecha, 2025)

It is not easy to justify the existence of a new positive low cloud feedback that began emerging in 2015, is not easy to justify. However, there are numerous natural climate signals during this period that are associated with atmospheric circulation changes that can influence the distribution of clouds:

- The 2014-2016 was one of the strongest El Niño events on record
- A cold anomaly beginning in 2015 in the subpolar gyre of the North Atlantic reflects a shift in the ocean circulation pattern associated with decadal variability in the Atlantic (Frajka-Williams *et al.*, 2017; Arthun *et al.* 2021).
- The Pacific Decadal Oscillation positive index peaked in 2016, then declined and has been in negative territory since late 2019
- Eruption of the submarine Hunga-Tonga volcano in 2022

Interannual cloud anomalies associated with the El Niño Southern Oscillation (ENSO) have a significant global signal and strong regional signals, especially over the tropical Indian and Pacific Oceans.

The Hunga Tonga eruption is remarkable in its coincidence with the exceptionally low value of planetary albedo in 2023. Goessling *et al.* (2024) found that the cloud perturbations in 2023 showed a different pattern from the overall pattern since 2015, with reduced cloud cover being most pronounced in the northern hemisphere and tropics. Regional reductions in cloud cover were most pronounced over the eastern Indian Ocean, over South America and extending over the eastern Pacific, as well as over northern North America, in the Southern Ocean around 60S, in the subtropical and eastern North Atlantic, and in parts of the North Pacific.

The Hunga Tonga eruption was unusual in that it injected large amounts of water vapor into the stratosphere, in addition to sulfate particles. Early publications focused on the impacts to stratospheric circulations and the direct radiative impact. In 2025, papers are emerging that examine the indirect effects of Hunga Tonga on surface climate using ensemble simulations from earth system models (Bednarz *et al.*, 2025; Kuchar *et al.*, 2025). These papers found statistically significant impacts on regional climates that were driven by circulation changes from couplings between the stratosphere and troposphere. These papers indicate the complex interactions between volcanic activity and climate dynamics. More research is needed to untangle any impacts of the Hunga Tonga eruption on the planetary albedo.

In summary, the decline in planetary albedo and the concurrent decline in cloudiness have emphasized the importance of clouds and their variations to global climate variability and change. A change of 1- to 2 percent in global cloud cover has a greater radiative impact on the climate than the direct radiative effect of doubling CO₂. While it is difficult to untangle causes of the recent trend, the competing explanations for the cause of the declining cloud cover have substantial implications for assessing the Equilibrium Climate Sensitivity and also for the attribution of the recent warming. An additional 10 years of data should help clarify whether this is a strong positive cloud feedback associated with warming, or a temporary fluctuation driven by natural variability.

8.5 Attribution of climate impact drivers

The IPCC (Ranasinghe *et al.* 2021) defines “climate impact drivers” or CIDs as “physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems.” Hence CIDs are those features of the weather and climate system of primary interest in assessing the impacts of climate change since they potentially affect humans and the natural world. For instance, under the heading “Heat and Cold,” CIDs are identified as mean air temperature, extreme heat, cold spells and frost. The IPCC

also points out that CIDs are not necessarily harm-related: depending on the system in question they can be detrimental, neutral, beneficial or a combination.

The first three columns of Table 12.12 in Ranasinghe *et al.* (2021, p. 1856), reproduced here as Table 8.1, summarizes the AR6 assessment of whether a signal of attributable anthropogenic influence has emerged across all major CIDs. One of the themes of this chapter is that attribution methods used by the IPCC tend to overstate the anthropogenic influence and understate the role of natural variability. Nonetheless a striking feature of that summary table is how few CIDs exhibit an anthropogenic signal sufficient to distinguish them from natural variability.

Out of the 33 weather impact categories listed, an anthropogenic signal is asserted with *high confidence* in only five, and with *medium confidence* in a further four. (Note that one of the CIDs is an increase in CO₂ levels, and since it is a tautology to attribute this to increased CO₂ levels this CID can be ignored.) For the rest the IPCC does not claim to have detected anthropogenic drivers. Of the five *high confidence assertions*, two are for changes in average temperatures (air and ocean) hence are not measures of extreme weather. Further, two of the four *medium confidence* assertions are related to ocean chemistry and thus are likewise not related to extreme weather. The IPCC does not assert a human influence on many non-temperature weather features such as wind, precipitation, flooding, or drought, ~~etc.~~

Other columns 2 and 3 of IPCC Table 12.12 report on whether anthropogenic signals are expected to emerge this century under RCP8.5, the most extreme forcing scenario. We have omitted these columns for several reasons. First, because they refer to whether climate models project detectable signals in the observations, which is a very different question than our concern here; whether a signal has been detected in historical data. Second, as we discuss in Chapter 4, the RCP8.5 scenario is a misleading and implausible high-end storyline, it is not a “base case” or business-as-usual projection. Third, the ensemble of detailed models is acknowledged (Palmer and Stevens 2019) to be “not fit for purpose” in describing regional changes and “unable to represent future conditions at the degree of spatial, temporal, and probabilistic precision with which projections are often provided.” (Nissan *et al.*, 2019). Even with these caveats, we note that the omitted columns in AR6 Table 12.12 show most weather impacts are not expected to exhibit an anthropogenic signal through the end of this century.

Climatic Impact-driver Type	Climatic Impact-driver Category	Already Emerged in Historical Period
Heat and Cold	Mean air temperature	1
	Extreme heat	2
	Cold spell	4
	Frost	
Wet and Dry	Mean precipitation	
	River flood	
	Heavy precipitation and pluvial flood	
	Landslide	
	Aridity	
	Hydrological drought	
	Agricultural and ecological drought	
	Fog weather	
Wind	Mean wind speed	
	Severe wind storm	
	Tropical cyclone	
	Sand and dust storm	
Snow and Ice	Snow, glacier and ice sheet	
	Permafrost	
	Lake, river and sea ice	11
	Heavy snowfall and ice storm	
	Hail	
	Snow avalanche	
Coastal	Relative sea level	
	Coastal flood	
	Coastal erosion	
Open Ocean	Mean ocean temperature	
	Marine heatwave	
	Ocean acidity	
	Ocean salinity	13
	Dissolved oxygen	14
Other	Air pollution weather	
	Atmospheric CO ₂ at surface	
	Radiation at surface	

High confidence of decrease

Medium confidence of decrease

Low confidence in direction of change

Medium confidence of increase

High confidence of increase

Table 8.1: Reproduction of column 1 of Table 12.12, IPCC AR6 Working Group I report. Emergence of anthropogenic signal in historical period for CIDs shown. White: no signal detected. Blue and orange: change detected (decrease or increase) and confidence level as indicated in color legend.